(6) B.S.

Technical Report PQTR-1046-77-6
Contract MDA903-77-C-0184
ARPA Order No. 3344
June 17, 1977

# AN INTERACTIVE COMPUTER AIDING SYSTEM FOR GROUP DECISION MAKING

STEVEN LEVIN
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Prepared For:

**DEFENSE ADVANCED RESEARCH PROJECTS AGENCY**
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This report describes progress on work centered on the demonstration of an interactive computer aid for group decision making.

The report includes: (1) a preliminary description of the problem scenario that will be used in evaluating the aiding system, (2) the group/machine procedures and dialogues, (3) key algorithms in the elicitation program, (5) progress in installing and intergrating computing and display resources. The next phase of the program will concentrate on the systems implementation and


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20. Abstract (continued)

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# 1. SUMMARY

## 1.1 Objectives

This report covers the first portion of a planned two-year program of research and development. The purpose of the program is to improve group decision making through the use of a computerized, interactive decision aiding system which essentially guides the decision making group through the problem at hand. The aiding methodology combines natural-language elicitation of decision trees, on-line sensitivity analysis, real-time assessment of multi-attribute values for decision outcomes, and direct visual feedback on areas of intra-group conflict. Such aiding allows the group to focus constantly on the decision path of greatest potential payoff, and on the critical differences of opinion along that path. As a result, the quality as well as the speed of group decision making is significantly enhanced.

The specific objectives of the program include the following:

(1) Develop computer programs for efficient, comprehensive, elicitation of decision trees from a decision making group.

(2) Develop computer programs for identifying structural and numerical differences among the contributions of individual group members, for merging these contributions and for resolving the points of conflict.

(3) Develop effective means for displaying to the group the results of the elicitation procedures and conflict analyses.

(4) Integrate the various programs and techniques into a complete aiding system which can be readily transferred to other test environments.

(5) Experimentally test the group decision aid, using a variety of representative military decision problems, to demonstrate its advantages under realistic conditions of use.

(6) On the basis of the development effort and the experimental results, establish guidelines and recommendations for future military applications of the group decision aiding methodology.

The program differs from previous and present decision aiding work in several ways. For one, it deals explicitly with the decision making group, rather than the individual decision maker. Secondly, it features the use of interactive computer support in the problem formulation phase of decision analysis, rather than in the optimization phase, as is the usual case. Furthermore, emphasis is placed on methods for guidance and control of communication between the group members. Third, and most important, it introduces new adaptive computer techniques, such as on-line sensitivity analysis, to the decision analysis process, and integrates these techniques with other computational approaches to form a complete decision aiding system.

## 1.2 Technical Approach

1.2.1 Problem Statement. Constant escalation in weapons cost and effectiveness, as well as the increasing complexity of international relations, makes military decision making more critical today than ever before. In today's military environment, most upper-level decisions are made by committees and staff groups. Typically, such groups contain experts from several speciality areas, who bring to the decision environment disparate sets of values. Decision time is usually limited, the decision making procedure is relatively unstructured, and intra-group conflicts arise on a broad variety of issues. Consequently the group is unable to consider the maximum set of alternatives, conflicts are not resolved in

an optimum manner, and the resultant decision is rarely up to the aggregate potential of the group membership.

Decision analysis offers a promising approach to solving these problems. The analytical procedure of building a decision tree formalizes the decision process, and permits incorporation of individual values (utilities) into the selection of alternative courses of action (Hays, O'Connor, Peterson, 1975). However, decision analysis as it is usually practiced is a highly personal and time-consuming process. Decision analysts are often called upon to assist in the solution of problems ranging over a large variety of domains. In most cases the decision analysts know far less about the problem-domain than do their clients. Thus their contributions are confined primarily to the phases of formalization and optimization. While optimization is usually computer assisted, the formalization phase invariably has been accomplished manually, using lengthy interviews of persons more familiar with the problem area. This approach is generally incompatible with the conditions of command group decision making.

Accordingly, it would be highly worthwhile to automate the formalization phase, using an interactive computer system to interrogate the group members and to construct a decision tree based on their responses. Leal and Pearl (1976) have shown that automated tree elicitation from individuals is feasible, and that on-line sensitivity analysis can be used to concentrate tree development on the branches with highest pay-off, thus streamlining the entire decision analysis process. Likewise, Gardiner and Edwards (1975) and Sheridan (1975) have shown that direct, real-time feedback of responses in group decision making focuses the effect on areas of real difference, while maintaining the advantages of full group participation. The supporting concepts and research evidence for an automated group decision aid are in existence.

1.2.2 Decision Aiding Methodology. The group decision aiding system incorporates four main elements. These are:

(1) Interactive elicitation of decision trees, including on-line sensitivity analysis.

(2) Multi-attribute analysis of group utility values at critical points in the tree.

(3) Computer support system, including continuous feedback of group decision responses by means of large-screen, color graphics display.

(4) Use of "intermediator" personnel to optimize interaction of the group with the aiding programs.

These elements are summarized briefly below.

Interactive Tree Elicitation. The basic procedures for interactively eliciting a decision tree structure are adapted from Leal's (1976) program for elicitation of individual decision structures. Leal's program uses an English-like conversational mode to build a decision tree by interrogating the decision maker regarding his decision alternatives, and the associated probabilities and utilities. Sensitivity analysis, based on heuristic tree search, is used to identify the most sensitive areas of the tree during the building process. This allows time and attention to be concentrated on expanding only the critical scenarios (sets of alternatives) within the large overall structure.

Automated tree elicitation can be applied to group decision making using two main elicitation modes.

(1) Elicit complete trees individually from all group members. Merge the individual trees during group interaction.

(2) Elicit a single group tree during group interaction.

Both modes have in common many programming requirements, but that the first mode involves considerably more technical difficulties, associated primarily with merging trees having inherent structural differences. On the whole, it is more cost-effective to implement the most practical mode first, evaluate it, and modify it or move on to the other on the basis of actual test data concerning group reaction and decision making performance. Accordingly, it was decided to implement the second mode -- single group trees -- during the first-year program, because this approach involves the most direct extension of existing software, the most powerful application of on-line sensitivity analysis, the most straightforward use of multi-attribute utility measurement, and consequently, the highest immediate chance of decision performance improvement. At the same time, it is planned to analyze further the technical details of tree merging, by means of a subcontract with CACI, Arlington, VA. In addition, the aiding program will be used to elicit trees from individuals for comparison with the group product. This analysis and comparison will provide insight into the potential advantages and problems associated with the elicitation and merger of complete individual trees.

<u>Multi-Attribute Utility Analysis</u>. One can expect several types of intra-group conflicts during the tree-building process. Conflicts regarding decision alternatives and their possible outcomes are easily resolved by merger or trimming. Conflicts regarding probabilities can also be handled in standard fashion. Conflicts regarding utilities, however, are anticipated to produce the most severe disagreements during group interactions, because they directly reflect differences in the value structures that group members

bring to the decision problem. In such cases, multi-attribute utility analysis provides a means for arriving at the required single utility by decomposing the specific alternative or outcome into its constituent attributes or dimensions.

Gardiner and Ford (1976), as well as Sheridan and Sicherman (1976), have shown that through group elucidation of values on each attribute separately, a more accurate picture of the utility conflict is achieved, and therefore agreement can be more readily reached. The process allows each decision maker to present his own viewpoint on the critical aspects of the problem, while leading the group as a whole to an eventual consensus. (Such a local decomposition is, of course, not necessary if everyone agrees immediately on global utility assignments for the set of alternatives.)

Support System. The group-aiding computer programs are being developed on a DEC PDP/11 minicomputer under the UNIX operating system. This insures maximum transferability of the programs among ARPA contractors and other potential military users. A version of the LISP programming language has been located which runs under UNIX. The tree elicitation program is presently written in LISP, and availability of this language will simplify its adaptation to the present application. Members of the decision making group will interact with the program through alphanumeric terminals. These units will be selected to permit quick entry and verification of numerical as well as written data. Feedback of decision information to the group as a whole will be by means of large-screen color display. Group displays will be provided by an Advent Videobeam™ color television projector. The Advent will be driven by a Genisco GCT-3000 color graphics system. The Genisco system is fully programmable for different character fonts, can display eight colors, and produces output compatible with the Advent projector. Chapter 6 describes progress in developing the necessary computing and display resources.

The Intermediator. A procedural, rather than technical, innovation is the proposed use of a trained "intermediator" to mediate between the aiding program and the actual decision makers. The intermediator is not a decision analyst, but is highly familiar with all program operations, and is consequently able to dispense with some of the lengthier man-computer dialogue necessary to elicit data from completely naive individuals. Sheridan (1975) has stressed the importance of the skilled moderator in successful applications of his Electronic Voting and Discussion Technique (EVDT). Preliminary discussions by Perceptronics with command-level military personnel revealed a quick acceptance of the intermediator concept as a means of overcoming resistance to computer aiding, and inefficiencies in the aiding process, which come from unfamiliarity with the interactive procedures themselves. If properly employed, the intermediator should help speed decision making while imposing no outside pressure on the decision making group.

1.2.3 Empirical Evaluation. The decision aiding methodology will be evaluated as it is developed, through observation of its use by representative decision-making groups in solving actual decision problems. The system factors which can be varied in such evaluation include:

(1) Tree Elicitation Mode
(2) Intermediator's Role
(3) Interactive Configuration
(4) Presentation Format
(5) Group Composition
(6) Decision Problem Area

Of these, the last, "decision problem area", is of particular interest. The decision problem area selected should: (a) be credible and of actual interest to the military as well as to the specific group; (b) involve

options that are already familiar to or easily explainable to the selected subject population; (c) reasonably complex, to allow a good number of alternative actions and move-response sequences, but not beyond several hours solution time; (d) have a value structure which includes significant judgmental elements.

One of the areas being considered for the initial year's effort is that of counter-terrorist activity. It is felt that this subject is current, important, and meets all of the above criteria. Chapter 2 describes progress in developing scenario materials for the first year evaluation program.

1.2.4 Effectiveness Analysis. It is expected that the proposed aiding technology will lead to a significant improvement in group decision making performance. Improvement will come from two sources:

(1) Decision Quality
(2) Decision Time.

These are treated separately in the following paragraphs.

Decision Quality. Improvement in decision quality is expected to arise from (1) increased participation of group members in the decision making process; and (2) the effects of multi-attribute decision modeling. A number of related studies have shown that better decisions follow fuller and more even participation of group members, and that direct feedback of decision responses facilitates group interaction. The group tree elicitation procedure insures full participation of the group, while the immediate response feedback through a large-screen graphics display provides the means for presentation and resolution of group conflicts. More complete explication of group opinion, a better route to consensus, and less "noisy" decisions, also result from the use of multi-attribute

modeling. And numerous studies, including several at Perceptronics, have shown that including a decision model in a closed-loop aiding system greatly improves the consistency and payoff of the resultant decisions.

Decision Time. Improvements in decision making time are expected from (1) reduced ambiguity in problem formulation due to computer guidance of discussions, (2) primary attention to critical decision areas through sensitivity analysis, and (3) efficient resolution of group conflicts through multi-attribute decision analysis and response feedback. Active computer guidance is the key to decision aiding success. Automatic specification of needed inputs minimizes the time spent floundering, defining terms, and clearing misunderstandings. Sensitivity analysis greatly reduces the area of the decision tree which must be investigated, thus reducing the associated discussion time. Finally, the time spent in resolving utility value disagreements is minimized by presenting cleanly the various attributes of the choice.

Improvement Ratio. Preliminary analysis of existing experimental data indicates an improvement ratio of between 4:1 and 9:1 for decision quality, and between 3:1 and 5:1 for decision time. Assuming a multiplicative relationship for the overall aiding system improvement ratio, we estimate a range of improvement in group decision making performance between 12:1 and 45:1. Taking into account that there is some interdependence of quality and time factors, we can use 25:1 as an initial estimate of overall performance improvement.

## 1.3 Program Accomplishments and Milestones

The first quarter of contract activity involved developing an initial problem scenario, designing the group/machine interaction, determining display formats, the modification and development of group

decision aiding algorithms, preliminary software design, installation and integration of hardware and software resources, and initial work on techniques for merging individual decision trees. The following specific tasks were accomplished during the past three months.

(1) For the purpose of identifying the characteristics of decision structures that the system should handle, a prototypical decision tree for a terrorist incident was developed.

(2) A study of the requirements posed by a group/machine decision aiding system was conducted and resulted in a "storybook" simulation detailing the displays and interactions between group members and the computer system.

(3) Algorithms were developed for aggregating individual probabilities into a single group probability and for using shifts in utility value at nodes as another parameter to the existing sensitivity algorithm.

(4) The preliminary software design for elicitation programs and the large screen display was completed. Detailed design of the system's elicitation procedures was begun.

(5) The PDP-11/45 computer system was installed and the UNIX operating system brought to an operational status. In addition, the Advent projection system, individual data entry terminals, and an intermediator terminal were installed and tested.

(6) Several meetings were held with personnel from CACI, Inc., to initiate research on the problem of merging individual decision trees.

The milestone chart for the contract program is shown in Table 1-1 with the report period illustrated as the shaded portion.

## 1.4 Next Period

The contract activity during the second quarter will primarily concentrate on the detailed design and implementation of the group decision aiding system. In addition, a problem scenario briefing book will be developed and experiments for evaluating the decision aiding system will be defined. The specific items of work for the next period include:

(1) Complete the detailed software design necessary to implement the group decision aiding system.

(2) Code and integrate major components of software design.

(3) Develop a handbook that will be used to brief participants on the simulated terrorist situation as part of the experiements for evaluating the effectiveness of the decision aiding system.

(4) Design preliminary experiments for evaluating the decision aiding system including measures of improved decision quality and decision time.

## 1.5 Report Organization

Chapter 2 describes the progress in generating problem scenarios for use in evaluating the group decision aiding system. Chapter 3 discusses the man/machine setting and procedures, and presents an initial description of group interactions and displays. Development of key algorithms for the

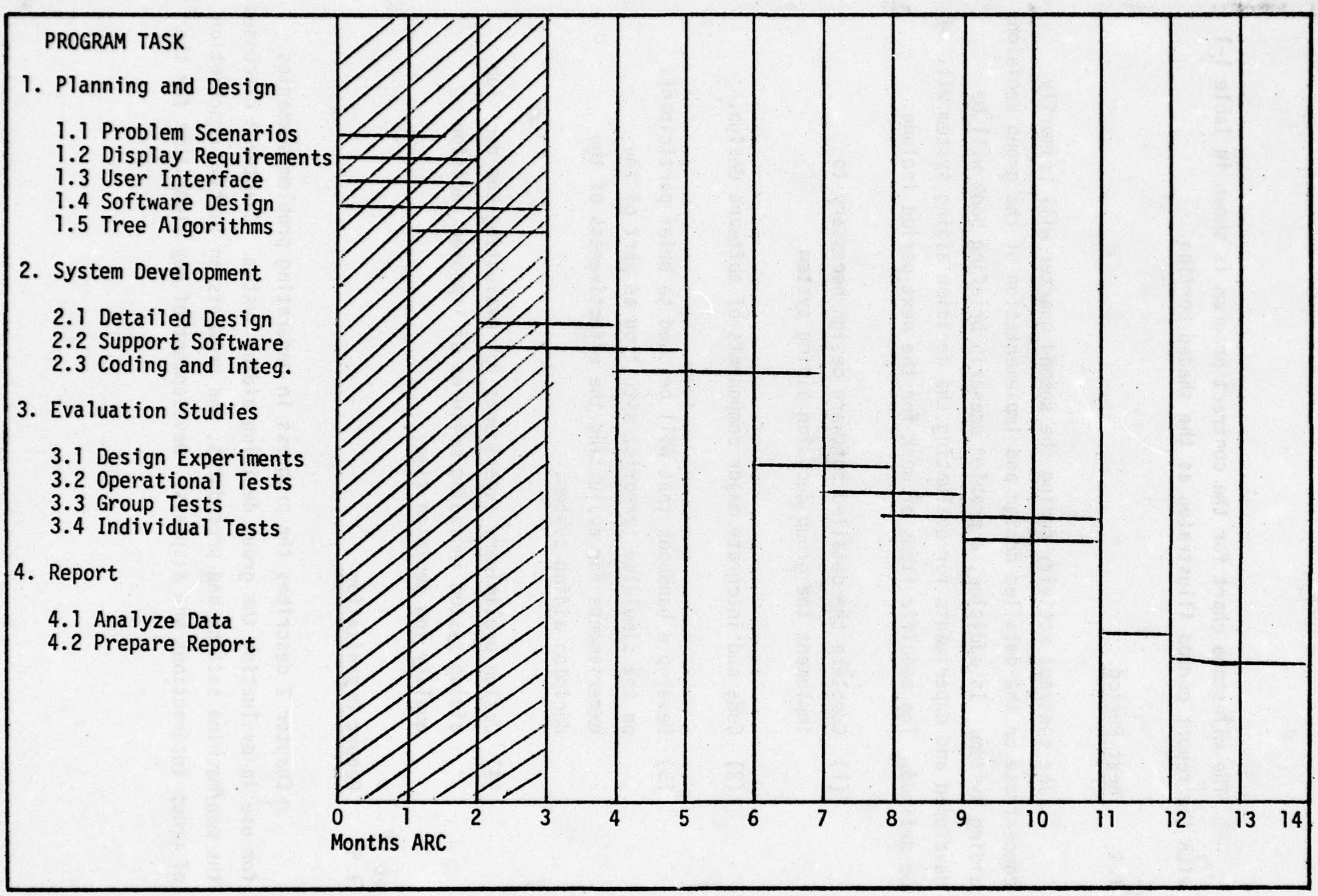



TABLE 1-1. PROGRAM MILESTONES

elicitation program are discussed in Chapter 4. Chapter 5 describes the software design and Chapter 6 the progress in installing and integrating computing and display resources. Subcontracted work is presented in Appendix A.

## 2. PROBLEM SCENARIO

In order to properly exercise the group decision aiding system with comprehensive experiments, a problem situation must be designed to serve as the background environment for the central decision-making task. Such a problem situation is called a "scenario" and is usually chosen to be compatible with as many system features as possible. The scenario currently being considered for the group decision-making environment is that of counter-terrorist actions. A terrorist scenario has a number of advantages with respect to the objectives of the current research:

(1) Decisions concerning counter-terrorist actions are normally made by a group.

(2) There is usually a time limit on discussion.

(3) By nature, the decision is very critical, often involving possible loss of life.

(4) Members of the group generally represent different interests and are thus more likely to have conflicts of value.

(5) The group members may have personal biases such as political image, etc.

The scenario is based on a hypothetical seizure by terrorists of an important installation (oil refinery, airplane, civic center, broadcasting station) and a subsequent group meeting of officials to develop a plan to resolve the situation. The terrorists are assumed to have made a list of demands and given a time limit for compliance. Various characteristics of the terrorists are known, such as their organization, their identities for most of them, and data on their previous actions.

A preliminary list of alternatives is immediately apparent:

(1) Accept demands
(2) Offer negotiation/no military plan
(3) Offer regotiation/plan delayed attacked
(4) Refuse negotiation/plan delayed attack
(5) Refuse negotiation/attack immediately

It is now incumbant upon the group to reach a decision as to which of the five available alternatives is best using the interactive group decision-aiding system. The final result will be a decision tree similar to the one shown in Figure 2-1 which outlines possible consequences to each available alternative along with group preference values (utilities) and estimates on the probability of occurence of various events.

The final decision tree not only serves to indicate which major alternative is best to follow, but also provides justification for this alternative by describing a plan of action to be carried out given the outcome of uncertain events. This plan is a much fuller justification of the group's decision than simple numerical comparisons of the major alternatives.

Other scenarios are being considered besides terrorist actions. Scenarios involving national emergencies such as earthquakes, floods, water shortages, etc. possess some of the same vital characteristics as those listed above without the international implications.

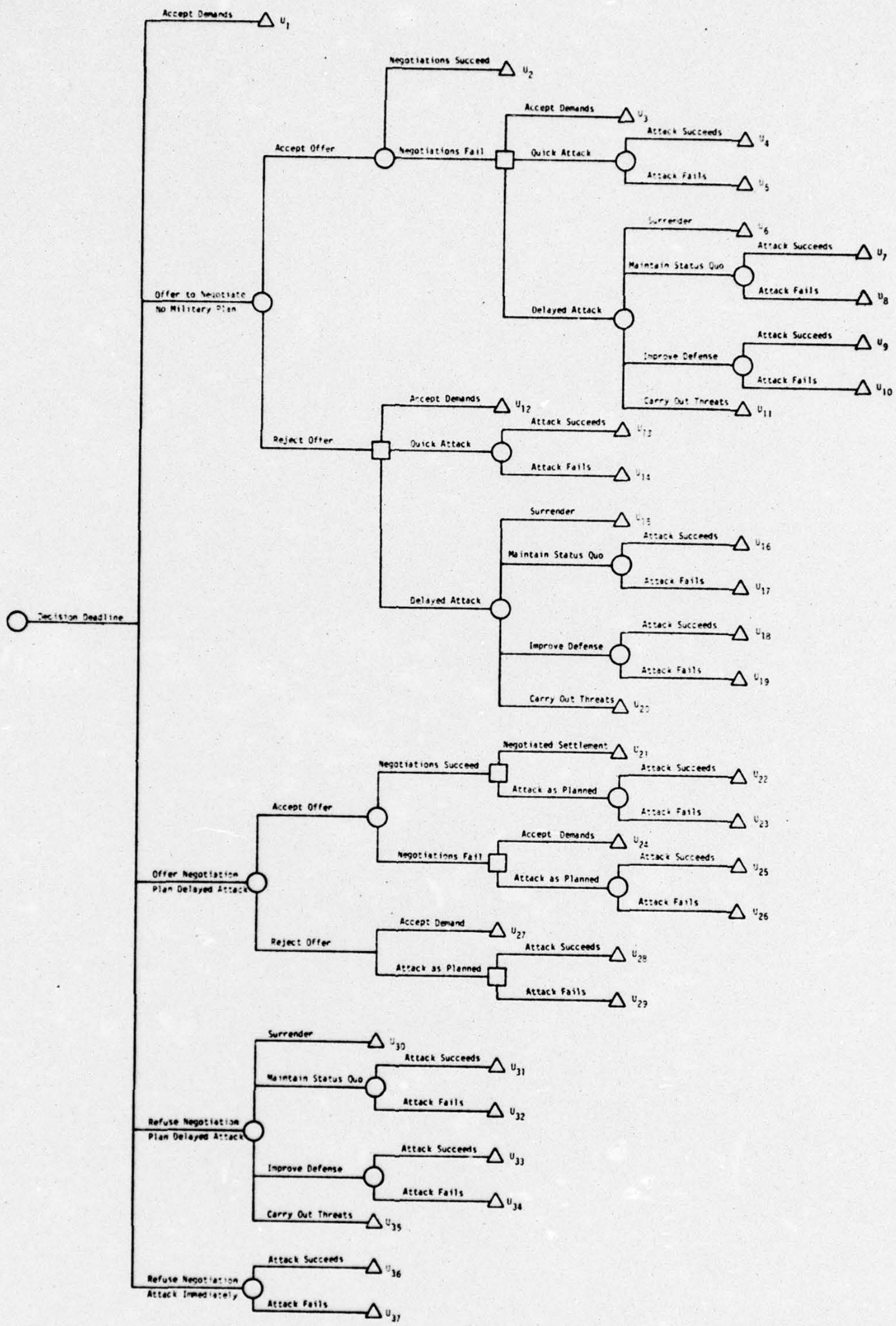



FIGURE 2-1. DECISION TREE

# 3. MAN/MACHINE INTERACTION

## 3.1 Introduction

This chapter presents an abbreviated step-by-step description of how the different group members and the computer would interact in using the group decision aid. The description is incomplete in that a full problem session is not covered, but does describe the form of system queries, displays, and user interactions under consideration. The current description is only a first version and is already undergoing substantial revision.

The description is presented as a set of successive frames, each of which describes the group's actions and the current group display. At several points there are references to notes which describe alternative displays and man/machine interactions. These notes appear in Section 3.4. In addition to the major group display frames, there are a set of frames that describe the intermediator's and director's man/machine dialogues which are not complete at present.

## 3.2 Group Members

The decision making group is composed of the participants, an intermediator, and a director. The participants are the decision makers. The intermediator and the director are procedural interfaces between the participants and the computer system.

The intermediator takes the participant's requests and formats them for input to the decision-aiding system. The inputs are lists of alternative actions and events, modifications to previously stored information, and commands for the display of selected information. The

director is an interface in the other direction. He takes the computer's output, often instructions as to what to do next, and presents them to the participants. The group director focuses the group's activities and insures that the group's inputs are appropriate for the decision aiding system. The major information flow among the group members and the computer system is shown in Figure 3-1.

For the initial system design each role (i.e., participant, intermediator, and director) is conceptualized as being performed by a separate individual. A future consideration will be to combine certain roles; for instance, combine the intermediator and director roles. Another possibility would be to make one of the participants the group director. Such changes may affect decisions on the form and content of individual and group displays. However, a design which makes each role independent will allow for relatively easy redefinition of system characteristics and greater flexibility in experimenting with different decision-aiding configurations. Finally, the decisions on group content are ultimately related to available personnel, cost, and most importantly, the sociology of group performance.

## 3.3 Description of Group/Machine Interaction

In the example which follows, a group of high level decision makers has been assembled to deal with a terrorist situation involving the seizure of property and hostages. We assume the decision aiding system has been demonstrated to the group at an earlier time. A director is present at the meeting to help the group reach a decision using the system. Also present is an intermediator who is a technician thoroughly trained in operating the system but who has no role in group proceedings. The intermediator may have to ask clarifying questions but has no direct inputs to group dialogues.

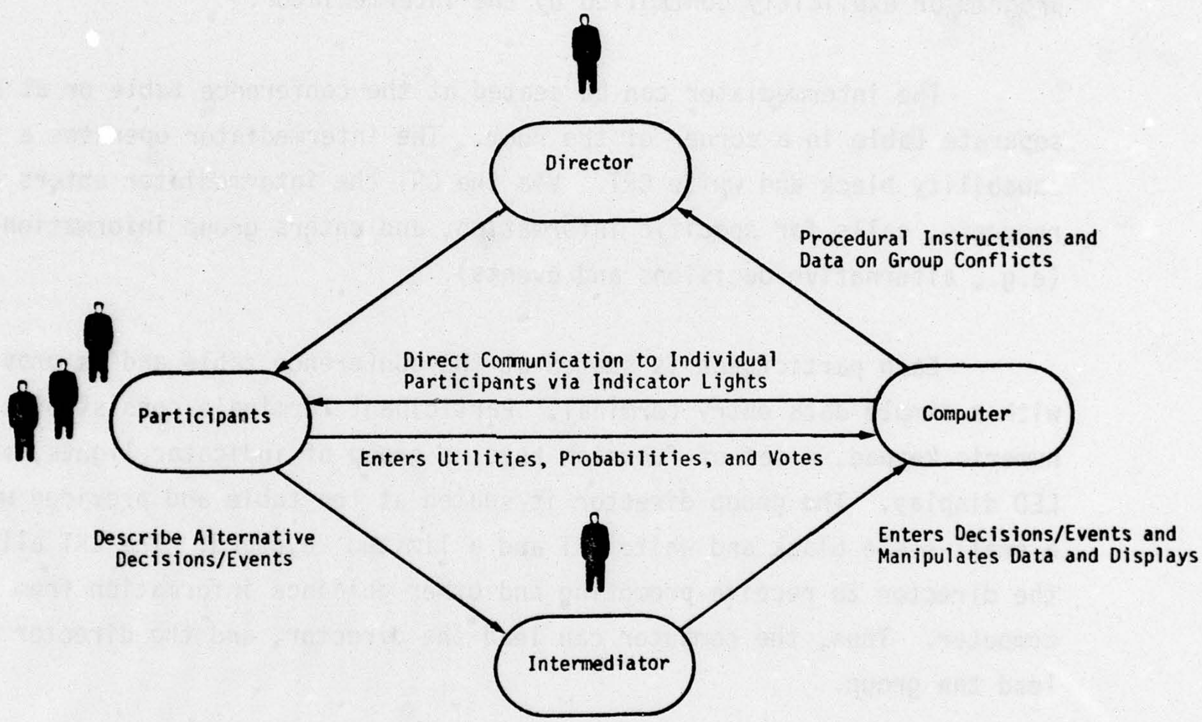



FIGURE 3-1. INFORMATION FLOW IN THE DECISION-MAKING SYSTEM

3.3.1 Group Decision Aiding Facility. The group meets in a conference room and is seated around a table. At one end of the room is a large screen onto which can be projected alphanumeric or graphical information in color or black and white. The contents of the display screen are computer generated and either automatically controlled by the system's elicitation program or explicitly controlled by the intermediator.

The intermediator can be seated at the conference table or at a separate table in a corner of the room. The intermediator operates a full capability black and white CRT. Via the CRT the intermediator enters group requests, calls for specific information, and enters group information (e.g., alternative decisions and events).

Each participant is seated at the conference table and is provided with a simple data entry terminal. Participant terminals consist of a numeric keypad, a set of function keys, a group of indicator lights, and a LED display. The group director is seated at the table and provided with a small-scale black and white CRT and a limited keyboard. The CRT allows the director to receive prompting and other guidance information from the computer. Thus, the computer can lead the director, and the director can lead the group.

3.3.2 Abbreviations. The following abbreviations are used to denote the group members or the entire group in the following description.

INT - Intermediator
PAR - Participant
DIR - Director
GRP - Entire Group

The display of information to a particular person or group is designated by the following symbols.

D - INT  Display on intermediator's terminal

D - DIR  Display on group director's terminal

D - PAR  Display on all participant terminals

D - $PAR_i$  Display only on the ith participant's terminal

D - GRP  Display on the large screen

Input operations are analogous to output operators except they are preceded by an I (i.e., I-INT).

THE INTERMEDIATOR STARTS UP THE COMPUTER PROGRAM. THE PROGRAM ASKS THE INTERMEDIATOR TO ENTER EACH PARTICIPANT'S NAME AND TERMINAL NUMBER. (INTERMEDIATOR: INITIALIZATION DIALOGUE)

THE PARTICIPANTS ARE THEN BRIEFED ON THE PROBLEM. THE BRIEFING MAY BE IN BOOKLET FORM OR USE A STORED COMPUTER/VIDEOTAPE MEDIA. A DISCUSSION MAY ARISE TO CLARIFY TO ALL PARTICIPANTS EXACTLY WHAT IS THE PROBLEM.

THE DIRECTOR NOW LEADS THE GROUP TO DECIDE UPON A COMMON UTILE RATING SCALE. THE SCALE RANGES FROM 0 TO 100 WHERE 0 IS THE WORST POSSIBLE STATE AND 100 IS THE BEST POSSIBLE STATE.

D - DIR: DISCUSS GROUP RATING PROCEDURE/SCALE.

D - GRP: INSTRUCTIONS ON MAKING UTILITY RATINGS.

VALUE ESTIMATION

YOU WILL BE ASKED TO ESTIMATE THE VALUE OF SITUATIONS ON A SCALE FROM 0 TO 100. THE WORST POSSIBLE STATE IS 0 AND THE BEST POSSIBLE STATE IS 100. WHILE EACH GROUP MEMBER MAKES HIS OWN ESTIMATE IT IS DESIRABLE FOR EVERYONE TO HAVE A COMMON UNDERSTANDING OF WHAT IS REPRESENTED BY THE WORST STATE AND THE BEST STATE.

ADDITIONAL INSTRUCTIONS ON UTILE RATING ARE DISPLAYED TO THE GROUP.

AS A BASIS FOR DISCUSSION A LIST OF SUGGESTED ATTRIBUTES RELATED TO THE PROBLEM'S OUTCOME WILL BE DISPLAYED. YOU MAY ADD, DELETE, OR CHANGE ITEMS IN THE ATTRIBUTE LIST. AFTER DECIDING ON A LIST OF ATTRIBUTES DISCUSS THE POSSIBLE VALUE ESTIMATES IN TERMS OF THOSE ATTRIBUTES.

AS A BASIS FOR DISCUSSION A LIST OF ATTRIBUTES PERTAINING TO THE CURRENT PROBLEM ARE DISPLAYED.

AT THIS POINT THE GROUP MAY WANT TO MODIFY THE ATTRIBUTE LIST. IF SO, THE INTERMEDIATOR MAKES THE NECESSARY CHANGES WHICH ARE REFLECTED ON THE GROUP DISPLAY.

THE SUGGESTED ATTRIBUTE LIST IS:

1. INTERNATIONAL REPERCUSSIONS
2. DOMESTIC REPERCUSSIONS
3. ADVANTAGE TO ENEMY
4. DIRECT COST
5. ECONOMIC COST
6. PERSONAL PRESTIGE
7. MORALITY

IF YOU WISH TO MODIFY THIS LIST PRESS THE YES KEY.

AS THE GROUP MODIFIES THE ATTRIBUTE LIST IT IS UPDATED BY THE INTERMEDIATOR AND DISPLAYED TO THE GROUP. WHEN THE GROUP FINISHES DISCUSSING THE ATTRIBUTE LIST THE COMPUTER IS TOLD TO PROCEED BY THE INTERMEDIATOR.

THE CURRENT ATTRIBUTE LIST IS:

1. INTERNATIONAL REPERCUSSIONS
2. DOMESTIC REPERCUSSIONS
3. ADVANTAGE TO ENEMY
4. DIRECT COST
5. ECONOMIC COST
6. PERSONAL PRESTIGE
7. MORALITY

THE GROUP THEN ASKED TO WEIGHT THE ATTRIBUTES (NOTE: ALTERNATIVELY, PARTICIPANTS COULD REDEFINE AND REWEIGHT THE ATTRIBUTE LIST EACH TIME IT WAS USED (AS IN A GROUP MULTI-ATTRIBUTE UTILITY MODEL).

D - GRP: INSTRUCTIONS ON HOW TO WEIGHT ATTRIBUTES.

YOU HAVE 100 POINTS TO DISTRIBUTE AMONG THE ATTRIBUTES. THE MORE POINTS YOU ASSIGN THE GREATER ITS IMPORTANCE IN THE CURRENT PROBLEM. TAKE A FEW MINUTES TO DECIDE HOW YOU WILL ASSIGN THE POINTS. AN EXAMPLE WEIGHTING IS SHOWN BELOW. PRESS THE SEND BUTTON WHEN YOU ARE READY TO ASSIGN WEIGHTS.

| | | |
|---|---|---|
| 1. | INTERNATIONAL REPERCUSSIONS | 15 |
| 2. | DOMESTIC REPERCUSSIONS | 35 |
| 3. | ADVANTAGE TO ENEMY | 10 |
| 4. | DIRECT COST | 15 |
| 5. | ECONOMIC COST | 20 |
| 6. | PERSONAL PRESTIGE | 0 |
| 7. | MORALITY | 5 |

WHEN THE PARTICIPANTS ARE READY, THE COMPUTER STEPS THROUGH THE ATTRIBUTE LIST WAITING UNTIL ALL PARTICIPANTS HAVE ENTERED A WEIGHT FOR THAT ATTRIBUTE. THE ATTRIBUTE BEING WEIGHTED IS HIGHLIGHTED (IN COLOR) BUT INDIVIDUAL WEIGHTS ARE NOT DISPLAYED TO THE GROUP (SEE NOTES 1 AND 2).

THE ATTRIBUTE TO BE WEIGHTED WILL BE INDICATED IN COLOR. ENTER YOUR WEIGHT FOR THE ATTRIBUTE AND PRESS THE SEND KEY.

1. INTERNATIONAL REPERCUSSIONS
2. DOMESTIC REPERCUSSIONS ← HIGHLIGHT ATTRIBUTE BEING WEIGHTED
3. ADVANTAGE TO ENEMY
4. DIRECT COST
5. ECONOMIC COST
6. PERSONAL PRESTIGE
7. MORALITY

THE DIRECTOR/COMPUTER BEGINS BY ASKING THE GROUP WHAT ALTERNATIVE ACTIONS COULD BE TAKEN AT THE POINT IN TIME UNDER CONSIDERATION.

D - DIR: ELICIT ACTION ALTERNATIVES FROM THE PARTICIPANTS.

WHAT ARE THE ALTERNATIVES OPEN TO US AT THIS TIME?

THE PARTICIPANTS SUGGEST A LIST OF ALTERNATIVES. ALTERNATIVES ARE ENTERED AND EDITED BY THE INTERMEDIATOR WHILE BEING DISPLAYED TO THE GROUP.
(INTERMEDIATOR: LIST ENTRY AND EDITING)

ALTERNATIVES

1. ACCEPT DEMANDS
2. OFFER TO NEGOTIATE/NO MILITARY PLAN
3. OFFER NEGOTIATION/PLAN DELAYED ATTACK
4. REFUSE NEGOTIATION/PLAN DELAYED ATTACK
5. REFUSE NEGOTIATION/ATTACK IMMEDIATELY

THE GROUP DISCUSSES THE ALTERNATIVE LIST, MAKING NECESSARY CHANGES VIA THE INTERMEDIATOR, UNTIL AN ACCEPTABLE LIST IS AGREED UPON.

WHEN THE LIST IS COMPLETE AND THE ALTERNATIVES ARE CHECKED TO BE MUTUALLY EXCLUSIVE THEN THE INTERMEDIATOR INSTRUCTS THE COMPUTER TO PROCEED.

D - DIR: PLEASE CHECK THAT ALL ALTERNATIVES ARE MUTUALLY EXCLUSIVE

I - INT: INSTRUCTS THE COMPUTER THAT THE ALTERNATIVE LIST IS COMPLETE

THE COMPUTER STEPS THROUGH THE ALTERNATIVES ASKING THE GROUP (EACH PARTICIPANT) TO ENTER A UTILITY VALUE FOR THE INDICATED ALTERNATIVE. THE SCALE IS THE PREVIOUSLY ESTABLISHED 0-100 UTILITY SCALE. (SEE NOTE 3)

NOW CONSIDER THE SITUATION "ACCEPT DEMANDS".
WHAT VALUE WOULD YOU GIVE TO THIS SITUATION?
ENTER A VALUE FROM 0 TO 100 AND PRESS THE SEND KEY.

1. ACCEPT DEMANDS

(HIGHLIGHT ALTERNATIVE UNDER CONSIDERATION IN COLOR)

2. OFFER TO NEGOTIATE/NO MILITARY PLAN
3. OFFER TO NEGOTIATE/PLAN DELAYED ATTACK
4. REFUSE NEGOTIATION/PLAN DELAYED ATTACK
5. REFUSE NEGOTIATION/ATTACK IMMEDIATELY

AFTER UTILITIES HAVE BEEN ELICITED FROM EACH PARTICIPANT FOR ALL OF THE ALTERNATIVES THE COMPUTER DISPLAYS INDIVIDUAL VALUES AND THE AGGREGATED GROUP VALUES. THE COMPUTER TELLS THE GROUP FOR WHICH ALTERNATIVES THERE IS CONSENSUS OR CONFLICT. (SEE NOTE 4)

INDIVIDUAL AND GROUP UTILITIES

| | ALTERNATIVE ACTIONS | D1 | D2 | D3 | D4 | GRP |
|---|---|---|---|---|---|---|
| 1. | ACCEPT DEMANDS | 30 | 35 | 30 | 45 | 35 |
| 2. | OFFER TO NEGOTIATE/NO MILITARY PLAN | 10 | 30 | 80 | 90 | 52.50 |
| 3. | OFFER TO NEGOTIATE/PLAN DELAYED ATTACK | 40 | 50 | A | 20 | 36.67 |
| 4. | REFUSE NEGOTIATION/PLAN DELAYED ATTACK | 60 | 20 | 20 | -- | -- |
| 5. | REFUSE NEGOTIATION/ATTACK IMMEDIATELY | 10 | 15 | 5 | 10 | 10 |

ACCEPTABLE CONSENSUS ON ALTERNATIVES 1, 3, AND 5.
CONFLICT ON ALTERNATIVE 2.
NO VALUE FOR ALTERNATIVE WITHOUT FURTHER EXPANSION OF THAT ALTERNATIVE.

AFTER DISPLAYING THE COMPUTER AGGREGATED GROUP UTILITIES, THE PARTICIPANTS MAY CHOOSE TO ACCEPT OR REJECT ONE OR ALL OF THE COMPUTER'S AGGREGATIONS. THE COMPUTER STEPS THROUGH THE ALTERNATIVES FOR WHICH THERE IS CONSENSUS AND EACH PARTICIPANT VOTES.

FOR THE INDICATED ACTION, PRESS THE YES KEY IF THE DISPLAYED GROUP VALUE IS ACCEPTABLE, OTHERWISE PRESS THE NO KEY.

INDIVIDUAL AND GROUP UTILITIES

| | ALTERNATIVE ACTIONS | D1 | D2 | D3 | D4 | GRP |
|---|---|---|---|---|---|---|
| 1. | ACCEPT DEMANDS | 30 | 35 | 30 | 45 | 35 |
| 2. | OFFER TO NEGOTIATE/NO MILITARY PLAN | 10 | 30 | 80 | 90 | 52.50 |
| 3. | OFFER TO NEGOTIATE/PLAN DELAYED ATTACK | 40 | 50 | A | 20 | 36.67 |
| 4. | REFUSE NEGOTIATION/PLAN DELAYED ATTACK | 60 | 20 | 20 | -- | -- |
| 5. | REFUSE NEGOTIATION/ATTACK IMMEDIATELY | 10 | 15 | 5 | 10 | 10 |

DEPENDING ON THE VOTE OUTCOME THE COMPUTER EITHER MARKS A BRANCH UTILITY AS REQUIRING FURTHER RESOLUTION OR RECORDS A GROUP UTILITY. IN THIS CASE WE ASSUME THE GROUP HAS AGREED WITH THE COMPUTER ON ALL THREE ALTERNATIVES. THE COMPUTER NOW DIRECTS THE GROUP IN RESOLVING THE CONFLICT ON ALTERNATIVE 2. (SEE NOTE 5)

THE COMPUTER NOW ASKS THE PARTICIPANTS TO ENTER A UTILITY FOR EACH ATTRIBUTE OF THE ALTERNATIVE BEING CONSIDERED. THERE ARE NO DELAYED EVALUATIONS, ALTHOUGH IT MAY BE DESIRABLE TO PERMIT ABSTENTIONS. THE SYSTEM PROMPTS ATTRIBUTE-BY-ATTRIBUTE AFTER EACH PARTICIPANT HAS MADE HIS RESPONSE. THE ATTRIBUTE (DIMENSION) UNDER EVALUATION IS HIGHLIGHTED.

PARTICIPANTS MUST ENTER A LEGAL RESPONSE (I.E., A NUMBER BETWEEN 0 AND 100) BEFORE THE SYSTEM PROCEEDS. ERRORS ARE REPORTED TO THE DIRECTOR AND SIGNALLED TO THE PARTICULAR PARTICIPANT VIA AN INDICATOR LIGHT.

THE COMPUTER PROMPTS PARTICIPANTS TO ENTER A UTILITY VALUE FOR EACH ATTRIBUTE.

ENTER YOUR ESTIMATE (0 TO 100) AND PRESS THE SEND KEY FOR THE INDICATED ATTRIBUTE OF THE SITUATION: OFFER TO NEGOTIATE/NO MILITARY PLAN.

1. INTERNATIONAL REPERCUSSIONS
2. DOMESTIC REPERCUSSIONS
3. ADVANTAGE TO ENEMY
4. DIRECT COST
5. ECONOMIC COST
6. PERSONAL PRESTIGE
7. MORALITY

HIGHLIGHT ATTRIBUTE BEING EVALUATED IN COLOR

ANOTHER POSSIBILITY IS TO DISPLAY A BREAKDOWN OF INDIVIDUAL PARTICIPANT UTILITIES AND WEIGHTS.

IF 56 IS ACCEPTABLE TO YOU AS THE VALUE FOR "OFFER TO NEGOTIATE/NO MILITARY PLAN" THEN PRESS THE YES KEY OTHERWISE PRESS THE NO KEY.

BREAKDOWN OF INDIVIDUAL UTILITIES AND WEIGHTINGS

| | D1<br>WEIGHT/UTILITY | D2<br>WEIGHT/UTILITY | | D4<br>WEIGHT/UTILITY |
|---|---|---|---|---|
| 1. INTERNATIONAL REPERCUSSIONS | .2/50 | .5/20 | | .3/40 |
| 2. DOMESTIC REPERCUSSIONS | .1/20 | .4/50 | | .1/20 |
| 3. ADVANTAGE TO ENEMY | .1/30 | 0/10 | | .1/70 |
| ⋮ | ⋮ | ⋮ | | ⋮ |
| 7. MORALITY | .3/20 | 0/30 | | .3/60 |
| UTILITY | 60 | 55 | .... | 53 |

GROUP UTILITY = 56

THE COMPUTER THEN CALCULATES AN OVERALL BRANCH UTILITY FOR EACH GROUP MEMBER USING A SIMPLE WEIGHTED AVERAGE.

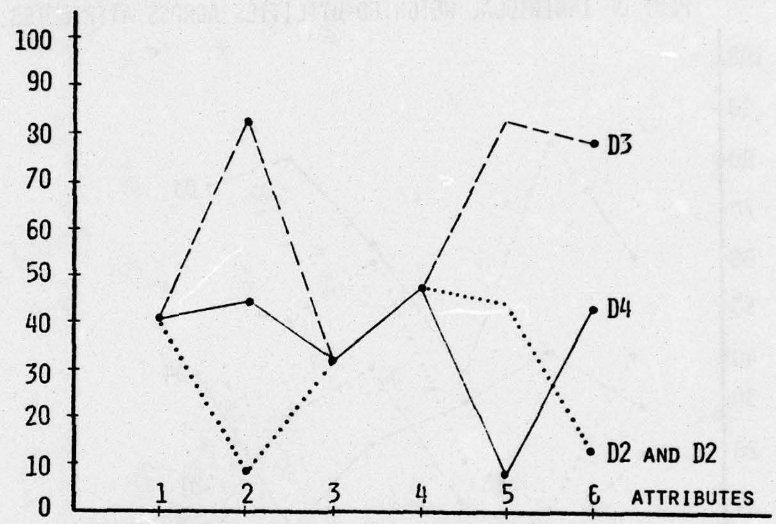
IF THE NEW BRANCH UTILITIES ARE CLOSE ENOUGH (REDUCED VARIANCE) THEN FURTHER DISCUSSION IS NOT NEEDED. FIRST, THE GROUP IS ASKED IF THE AGGREGATED VALUE IS ACCEPTABLE.

IF 56 IS ACCEPTABLE TO YOU AS THE VALUE FOR "OFFER TO NEGOTIATE/ NO MILITARY PLAN" THEN PRESS THE YES KEY; OTHERWISE PRESS THE NO KEY.

ACTION: OFFER TO NEGOTIATE/NO MILITARY PLAN.

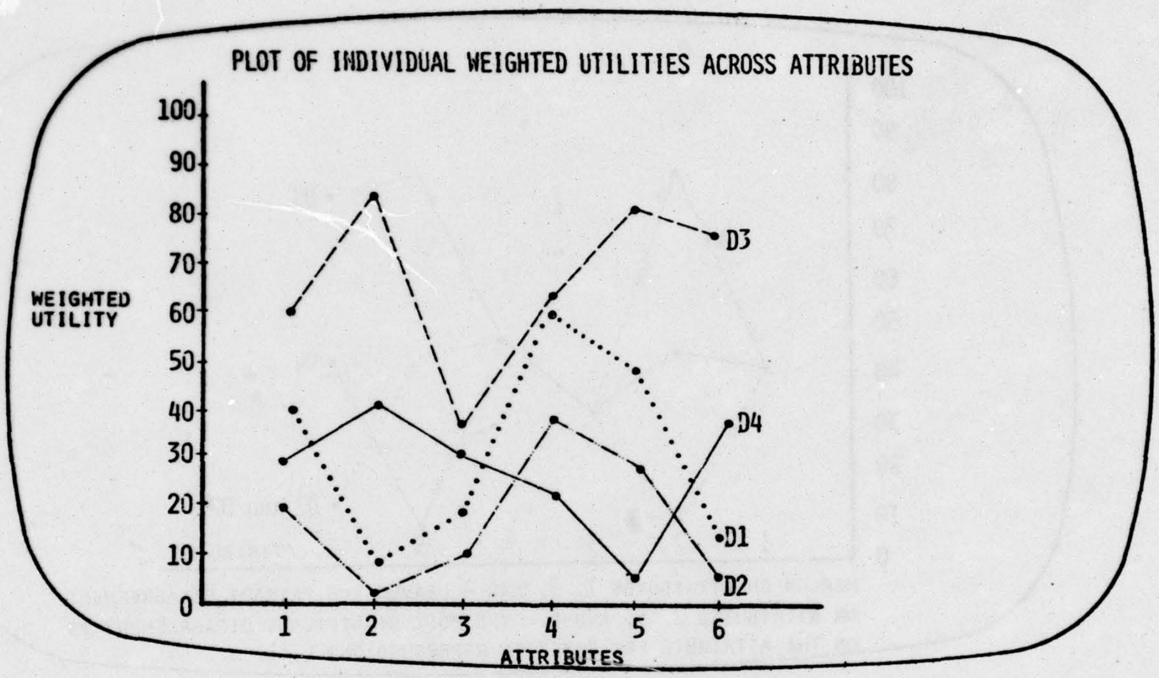
| D1 | D2 | D3 | D4 | GRP |
|---|---|---|---|---|
| 60 | 55 | 63 | 53 | 56 |

AFTER DOING THE MERGE OF D1 AND D2 THE GROUP NOW SEES THAT THERE IS FAIRLY CLOSE AGREEMENT ON SOME ATTRIBUTES AND NOT OTHERS. TO MAKE THIS CLEARER, THE DISPLAY IS MERGED ON ATTRIBUTES 1, 3, AND 4.

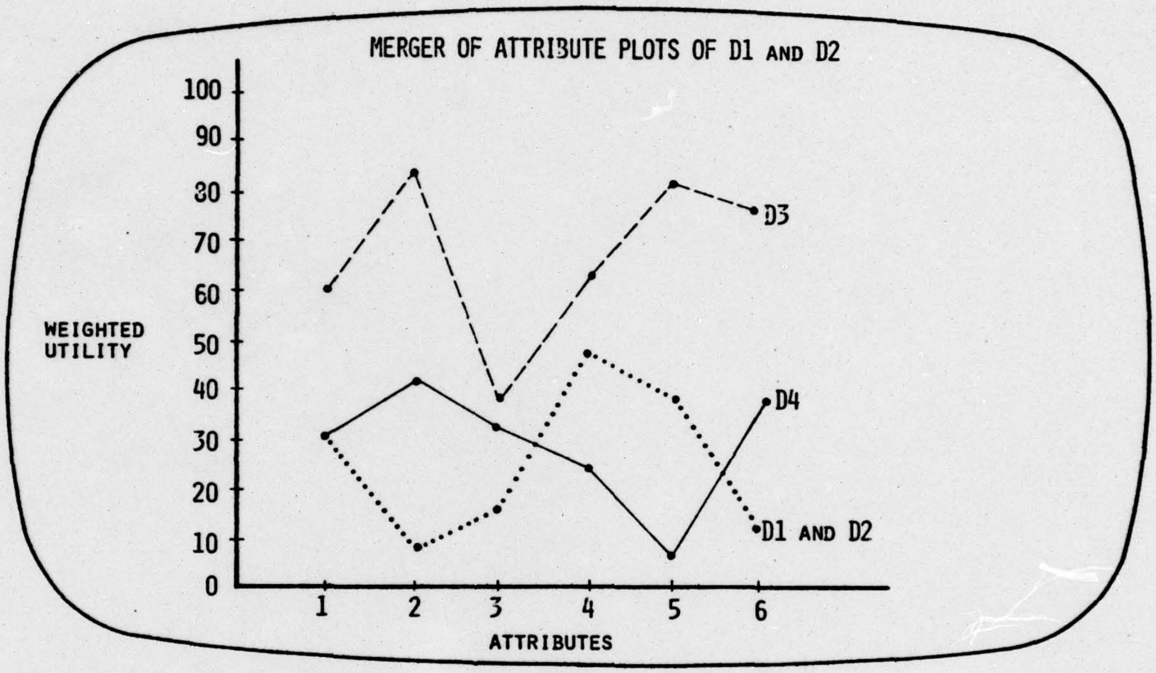



MERGER ON ATTRIBUTES 1, 3, AND 4 LEAVES THE PRIMARY DISAGREEMENT ON ATTRIBUTES 2, 5, AND 6. THE MOST SIGNIFICANT DISAGREEMENT IS ON THE ATTRIBUTE FOR DOMESTIC REPERCUSSIONS (#2).

IF THERE IS NOT AN ACCEPTABLE GROUP UTILITY (BY THE ESTABLISHED THRESHOLD VALUE OR BY THE VOTING RESULTS) THE COMPUTER IS USED TO IDENTIFY THE BASIS FOR THE DISAGREEMENT. IS THERE A CONSTANT UTILITY BIAS? IS THERE A UTILITY DISAGREEMENT ON A SPECIFIC ATTRIBUTE? A GOOD STARTING POINT IS TO DISPLAY A PLOT OF THE WEIGHTED UTILITIES FOR EACH PARTICIPANT ON THE DIFFERENT ATTRIBUTES.



AFTER PLOTTING THE INDIVIDUAL UTILITIES THE GROUP MIGHT RECOGNIZE THAT PARTICIPANTS D1 AND D2 ARE VERY CLOSE AND HAVE THE INTERMEDIATOR MERGE THOSE TWO PERSONS WEIGHTINGS. (INTERMEDIATOR: MAUM PROCEDURES)



THE DIRECTOR WOULD THEN SUGGEST THAT THE GROUP DISCUSS THE ATTRIBUTES IN CONFLICT. AGREED UPON VALUES FOR THE ATTRIBUTES ARE THEN AGGREGATED TO FORM A SINGLE BRANCH UTILITY.

AT THIS POINT UTILITIES HAVE BEEN ASSIGNED TO EACH DECISION BRANCH AND THE COMPUTER PROCEEDS TO EXPAND ANOTHER NODE.

IN THIS PARTICULAR CASE THE TIP NODE THAT WILL BE EXPANDED IS "REFUSE NEGOTIATION/PLAN DELAYED ATTACK" BECAUSE ITS VALUE WAS NOT AGREED UPON IN THE PRECEDING DISCUSSION. THE COMPUTER WILL ALWAYS GIVE FIRST PRIORITY TO AND INSIST ON EXPANDING NODES WHERE UTILITY ASSESSMENTS HAVE BEEN DEFERRED. HOWEVER, VALUE DEFERMENTS CAN ONLY BE MADE FOR ONE LEVEL. IN OTHER CASES THE SYSTEM ALWAYS EXPANDS THE TREE TO TWO LEVELS BEFORE MAKING NODE EXPANSION A FUNCTION OF THE SENSITIVITY ALGORITHM.

THE COMPUTER NOW SEEKS TO DETERMINE IF THE TIP NODE WILL BE A SET OF ACTIONS (DECISIONS) OR EVENTS. THE QUESTION IS POSED TO THE GROUP BUT THE DIRECTOR SUPPLIES THE RESPONSE (I.E., THIS IS NOT A VOTE).

ASSUMING THAT WE "REFUSE NEGOTIATIONS/PLAN DELAYED ATTACK",
IS THERE A CHOICE OF ALTERNATIVE ACTIONS AVAILABLE?

ASSUMING THE DIRECTOR RESPONDS "NO", THE COMPUTER ASKS IF THERE ARE SOME EVENTS THAT MAY OCCUR. AGAIN, THE DIRECTOR SUPPLIES THE GROUPS RESPONSE.

ASSUMING THAT WE

"REFUSE NEGOTIATIONS/PLAN DELAYED ATTACK"

ARE THERE SOME EVENTS THAT MAY HAPPEN?

ASSUMING THE GROUP AGREES THERE ARE SOME POSSIBLE EVENTS THE COMPUTER PROCEEDS TO ELICIT A LIST OF EVENTS IN THE SAME WAY THAT A LIST OF ALTERNATIVE GROUP ACTIONS WERE ELICITED PREVIOUSLY (INTERMEDIATOR: ALTERNATIVE ENTRY AND EDITING)

ASSUMING THAT WE "REFUSE NEGOTIATIONS/PLAN DELAYED ATTACK" THE POSSIBLE EVENTS ARE:

1. ACCEPT OFFER
2. REJECT OFFER

THE PARTICIPANTS ARE NOW ASKED TO ASSIGN UTILITIES AND PROBABILITIES TO THE ALTERNATIVE EVENTS. (SEE NOTES 6 AND 7)

ASSUMING WE "REFUSE NEGOTIATION/PLAN DELAYED ATTACK" THE POSSIBLE EVENTS ARE:

1. ACCEPT OFFER

2. REJECT OFFER

HIGHLIGHT THE EVENT BEING EVALUATED BY COLOR

ENTER THE VALUE (A NUMBER BETWEEN 0 AND 100) YOU WOULD GIVE TO THE EVENT "ACCEPT OFFER" AND PRESS THE SEND KEY.

WHAT ARE THE CHANCES THIS EVENT WILL OCCUR?

ENTER A NUMBER BETWEEN 0 AND 1 AND PRESS THE SEND KEY.

THE COMPUTER ELICITS A VALUE/PROBABILITY PAR FOR THE REMAINING EVENTS AND THEN DISPLAYS THE AGGREGATED RESULTS TO THE GROUP.

ASSUMING WE "REFUSE NEGOTIATION/PLAN DELAYED ATTACK":

| | | D1 | | D2 | | D3 | | GRP | |
|---|---|---|---|---|---|---|---|---|---|
| | EVENTS | UTILITY | PROB | UTILITY | PROB | UTILITY | PROB | UTILITY | PROB |
| 1. | ACCEPT OFFER | 25 | .7 | 45 | .6 | 30 | .7 | 33 | .66 |
| 2. | REJECT OFFER | 40 | .3 | 45 | .4 | 35 | .3 | 40 | .33 |

THERE IS GOOD GROUP AGREEMENT ON THE VALUE AND PROBABILITY ESTIMATES OF ALL EVENTS.

AFTER DISPLAYING THE COMPUTER AGGREGATED UTILITIES AND PROBABILITIES, THE PARTICIPANTS MAY CHOOSE TO REJECT ONE OR ALL OF THE AGGREGATIONS. THE COMPUTER STEPS THROUGH THE VALUES ASKING THE PARTICIPANTS TO VOTE THEIR ACCEPTANCE.

FOR THE INDICATED VALUE, PRESS THE YES KEY IF THE DISPLAY GROUP VALUE IS ACCEPTABLE, OTHERWISE PRESS THE NO KEY.

THE COMPUTER WOULD NOW PROCEED TO EXPAND ANOTHER NODE BY FIRST FINDING OUT IF ANY EVENTS ARE ABOUT TO HAPPEN. AS BEFORE, THE DIRECTOR INPUTS THE GROUP RESPONSE.

ASSUMING WE "ACCEPT DEMANDS" ARE THERE EVENTS ABOUT TO OCCUR OVER WHICH WE HAVE NO CONTROL?

ASSUMING NO EVENTS, THE COMPUTER QUESTIONS THE GROUP ABOUT POSSIBLE ACTIONS. THE DIRECTOR ENTERS A YES/NO RESPONSE.

DO WE HAVE A CHOICE OF ALTERNATIVE ACTIONS THAT COULD BE TAKEN AT THIS POINT?

SINCE THE GROUP DOES NOT WANT TO EXPAND THIS NODE FURTHER, THE COMPUTER SELECTS ANOTHER NODE AND THE TREE ELICITATION PROCESS CONTINUES.

WHEN THE GROUP (OR COMPUTER) DECIDES TO HALT THE ELICITATION PROCESS THE BEST TREE PATH IS DISPLAYED TO THE GROUP.

### 3.4 Notes on Group/Machine Interaction

Note 1: An alternative procedure is for the participants to give their weightings to the intermediator and have him enter them. This would be cumbersome and probably not as individualistic or inviting to the participants.

Note 2: When participants enter attribute weights three conditions may arise.

(1) The participants' weights may sum to 100.

(2) The participants' weights may not sum to 100.

(3) The participant recognizes, belatedly, an error in entering this weights.

For Condition 1, no action is necessary.

For Condition 2, the participant is notified via an indicator light that an error exists and asked to hand a corrected list to the intermediator.

D-$PAR_j$: Error in attribute weight assignment.
D-DIR: $PAR_j$ has error in weight assignments.

An alternative correction technique is to display each value to the participant and have him confirm that value by just pressing the SEND button and correct by entering a new value and pressing the SEND button.

The disadvantage of both procedures is that the participant cannot get a complete view of all his weights except on the group display.

<u>For Condition 3</u>, as with the entry of utilities, there is little the participant could do directly. The intermediator should be given the capability to display and edit each participant's weights so that he (the intermediator) can make corrections.

Note 3: Five conditions may result when participants are asked to enter utility values.

(1) A participant may enter a legal data value.

(2) A participant may enter an illegal (out of range) utility value.

(3) A participant may wish to delay entering any value until that node is expanded.

(4) A participant may abstain, enter no utility value, for an alternative.

(5) A participant makes an error of commission and enters a value in the correct range but not the intended value.

<u>For Condition 1</u>, no further immediate action is required.

<u>For Condition 2</u>, an indicator light goes on for the participants who have entered illegal values. Both the intermediator and director are informed of illegal values via their CRTs. Participants in error must enter a legal response before the computer proceeds.

| | |
|---|---|
| D-PAR: | Lite illegal value entry panel. |
| D-INT/DIR: | Illegal entry for utility value by name/location. |
| I-PAR: | Participant enters new utility value. |

<u>For Condition 3</u>, the system might

(1) Take no further action and proceed to elicit utility values for any remaining alternative;

(2) Proceed to expand that node immediately before values are obtained for the remaining alternatives; or

(3) Let the group decide whether to expand the node or go on to elicit other values.

Since a context for assigning values to the alternatives at the node has been established, the system will always attempt to elicit the remaining branch utilities (i.e., option 1).

<u>For Condition 4</u>, a flag indicating the participant has abstained is set and values are elicited for the remaining branches.

<u>For Condition 5</u>, the system might allow the participant to cancel his last input by pressing a cancel button and reentering the data. Initially, this poses unnecessary technical and procedural problems and will not be permitted. If this turns out to be a problem, it can be reconciled later.

Another possibility is for the computer to await a confirmation signal from the director giving participants an opportunity to cancel their last input and provide a replacement value.

Note: 4 Alternatives for displaying individual/group utility values:

(1) As each alternative is considered, the values input by each participant are displayed on the group display. A group value is also computed and displayed. If the group value is acceptable (by some threshold and value) it is displayed in green.

(2) Only a group value is displayed and only if it is an acceptable value by the threshold measure. This is done as alternatives are considered.

(3) Each of the alternatives are considered and values are entered by the participants. The system then displays each participant's utilities and the aggregated group value for all of the alternatives.

(4) Same as (3) except only the group value is displayed.

Use alternative 3. Alternative three would eliminate some inter- and intra-person bias that might be generated if utilities were explicitly displayed while alternatives were being evaluated. Disadvantages: (1) there are probably negative effects to displaying individual utilities, and (2) the participants do not have a visual record of how they evaluated preceding alternatives.

Note 5: The participants could not

(1) Resolve conflicts of value or

(2) Expand nodes on which one or more participants have delayed their evaluation.

Option 1 has the advantage that it retains the most continuity of group action and is suggested. Option 2 would require a new set of alternatives and values.

Note 6: Individual plots can be identified by the symbol used with different colors. An area for further work is computer-based procedures for identifying major conflict points. A simple approach to identifying conflicts is to rank the variance across attributes and present the participants with a ranking an amount of disagrement. Another technique is to provide a set of commands for merging the weighted utilities.

Note 7: Alternatives for eliciting this information are:

(1) Elicit all of the utilities and then the probabilities, or vice versa.

(2) Elicit a utility/probability pair for each event.

One could argue that context is preserved by both approaches. Alternative 2 appears to be a reasonable choice for the initial system.

Another issue is how and when to display the elicited information. The recommended approach is to display the elicited values and aggregated group values after all of the necessary and probabilities have been elicited. Whatever solution is adopted should be compatible with that adopted for eliciting utilities on alternative group actions (decision modes).

Note 8: Conditions related to the entry of utility estimates have already been considered. For probabilities the following conditions may arise:

(1) The participant enters a legal probability value Pi where $0 \leq Pi \leq 100$ and $\sum_{K-1,n} Pi = 100$ where n is the number of alternative events.

(2) The participant enters an illegal probability estimate.

(3) The participant abstains.

(4) The participant makes an error of commission.

For Condition 1, no further immediate action is required.

For Condition 2, an indicator light goes on for the participants who have entered illegal values. If the error is only in the last value entered, the participant can correct it immediately. Otherwise, he may ask the intermediator to make more extensive corrections. Participants in error must enter a legal response before the system proceeds.

For Condition 3, a flag is set indicating the participant has abstained and the remaining probabilities are elicited.

For Condition 4, there is no corrective action at present.

After an attribute list is established, a list of attributes should be given to each participant. This list could be printed from the modified list on an available printer or preprinted and modified by the participants. Rationale: The participants will subsequently be asked in MAUM procedures to assign values to attributes. This is most easily done when the entire attribute set is available.

# 4. ALGORITHM DEVELOPMENT

## 4.1 Probability Assessment

4.1.1 Overview of the Problem. Maximization of expected utility is taken to be the foundation for group decision making. However, unlike the individual decision making case, the group must come to an agreement about its utility and probability estimates for various alternatives and event outcomes. If a group estimate is to be obtained by a mathematical combination of individual estimates, rather than by agrument alone, an aggregation method must be defined. Such a method need not produce the "correct" aggregation value. It is only necessary to approximate it and leave the group an opportunity to change it.

The following discussion centers on the problem of aggregating individual probability estimates into a group estimate as it relates to the individual backgrounds of the group members.

4.1.2 Analysis of Group Probability Assessment. Consider a decision-making group made up of individuals $I_1, \ldots, I_m$ attempting to arrive at a group judgment of the probabilities of various outcomes to a particular event by aggregating individual estimates. Figure 4-1 shows the individual estimates for the probabilities $P_1, \ldots, P_n$ of the outcomes of the event. Each $P_{ij}$ in the matrix is the estimate of individual $I_i$ for outcome $E_j$.

One simple method to arrive at the aggregated probabilities is by averaging. However, if a single formula is used for all groups, it will not take into consideration the variation in backgrounds of the individual group members. Two extreme group types can be identified with respect to individual background and experience. In one case, all group members possess exactly the same background and experience with respect to the

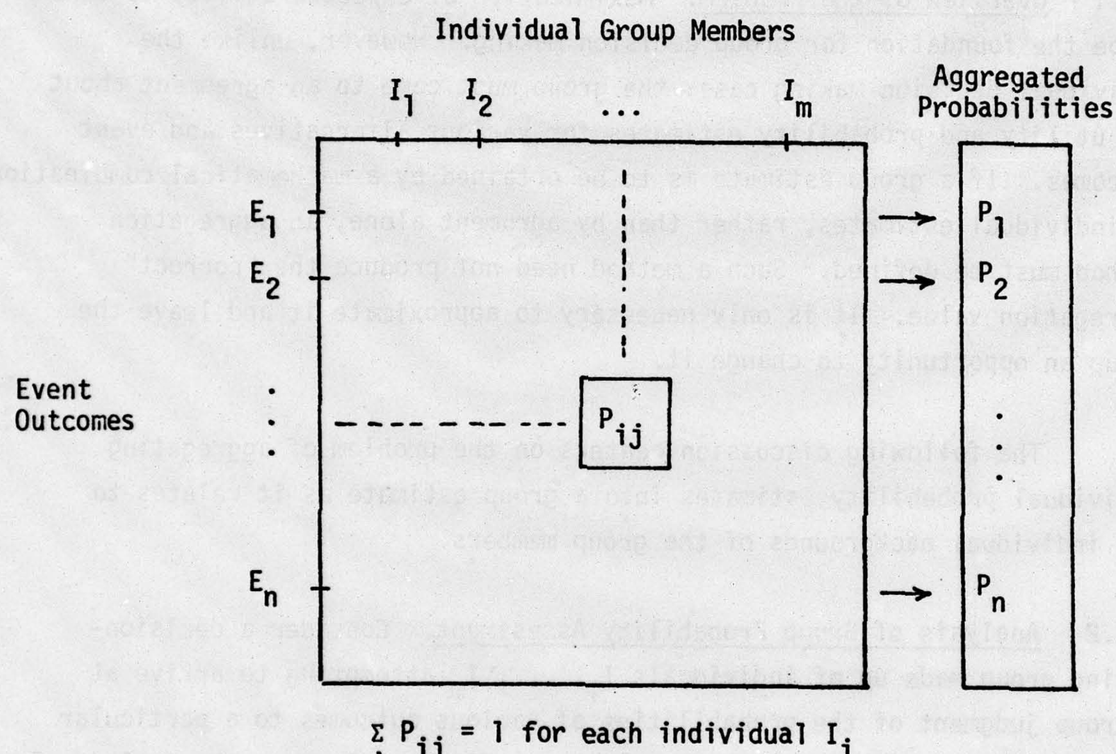



FIGURE 4-1. GROUP PROBABILITY ESTIMATES

problem area. In this case, combining the probability estimates becomes one of conflict resolution. An example of this is when two or more military personnel discuss strategic or tactical plans. Their objectives and background are the same. However, the other extreme is when the individuals in the group have mutually exclusive backgrounds and experience. The combination of probability estimates is then one of aggregation. For example, a group discussing anti-terrorist actions may consist of military, political, and economic members. Their objectives and goals may be entirely different.

It seems logical, then, to have different value combination formulas for the different types of groups depending upon whether conflict resolution or aggregation is the motive. Most groups, however, do not fall at the extreme ends of this spectrum. Figure 4-2 shows the full spectrum of group types from one extreme to the other. An indicator $\delta$ ranging from 0 to 1 is sufficient to *locate* a particular group on the scale. The value of $\delta$ for a particular group corresponds to the inter-correlation of background knowledge and can be estimated by experiment and questioning before the group convenes.

The contributions of group members with identical backgrounds can be considered to originate from the same underlying philosophies. That is, all of the group members see the problem from the same viewpoint. As an example of this, suppose that a group is composed of three individuals: Mr. White, Mr. Brown, and Mr. Black, who are to view a cube and report its apparent color. Figure 4-3 shows this situation. Assume further that Mr. White reports the color to be white; Mr. Brown reports brown; and Mr. Black reports black. This is clearly a conflict and it would be reasonable to try to reach an agreement by means of conflict resolution. In this case, averaging is appropriate and a final group judgment of "brown" would seem acceptable.

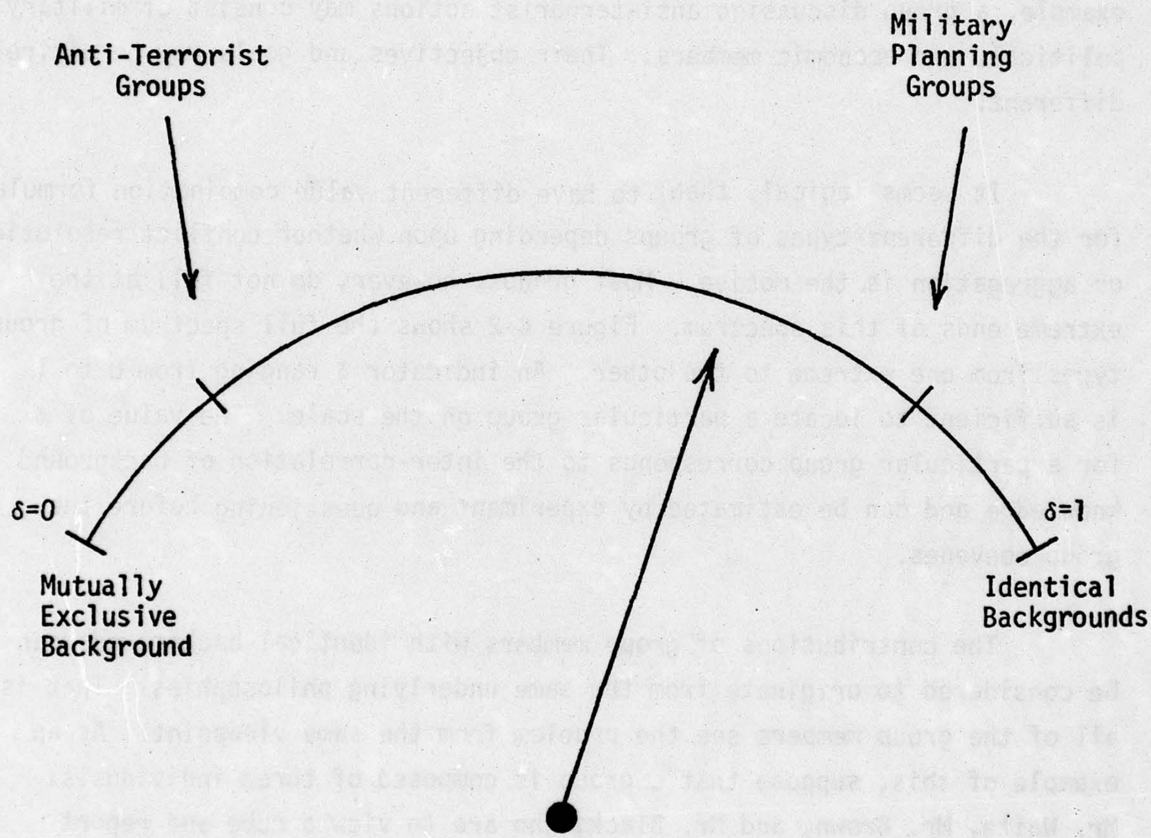



FIGURE 4-2. SPECTRUM OF GROUP TYPES

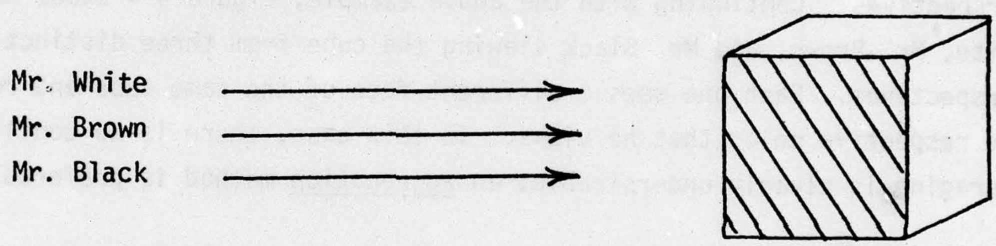



FIGURE 4-3. IDENTICAL PERSPECTIVE

In the case of probability estimates, averaging results in the following formula (Figure 4-1):

$$P_j = \frac{\sum_i P_{ij}}{m}$$

which would be applicable when $\delta = 1$.

In the other extreme case, the group participants have mutually exclusive backgrounds. That is, they view the problem from different perspectives. Continuing with the above example, Figure 4-4 shows Mr. White, Mr. Brown, and Mr. Black viewing the cube from three distinct perspectives. Each one sees a different face of the same cube and reports the respective color that he views. In this case, there is no conflict. Averaging is clearly undersirable; an aggregation method is preferable.

The viewpoints of the three group members can be considered "orthogonal" as shown in Figure 4-5. This suggests a vector-approach to probability aggregation. The formula for probability combination for $\delta = 0$ is then:

$$P_j = \sqrt{\sum_i P_{ij}^2}$$

Considering the probability estimates as vectors in a hyper-space does not produce a normalized result. That is, after computation, the $\sum_j P_j$ does not equal 1. Therefore, a normalization procedure must be applied:

$$P_j = \frac{\sqrt{\sum_i P_{ij}^2}}{\sum_j \sqrt{\sum_i P_{ij}^2}}$$

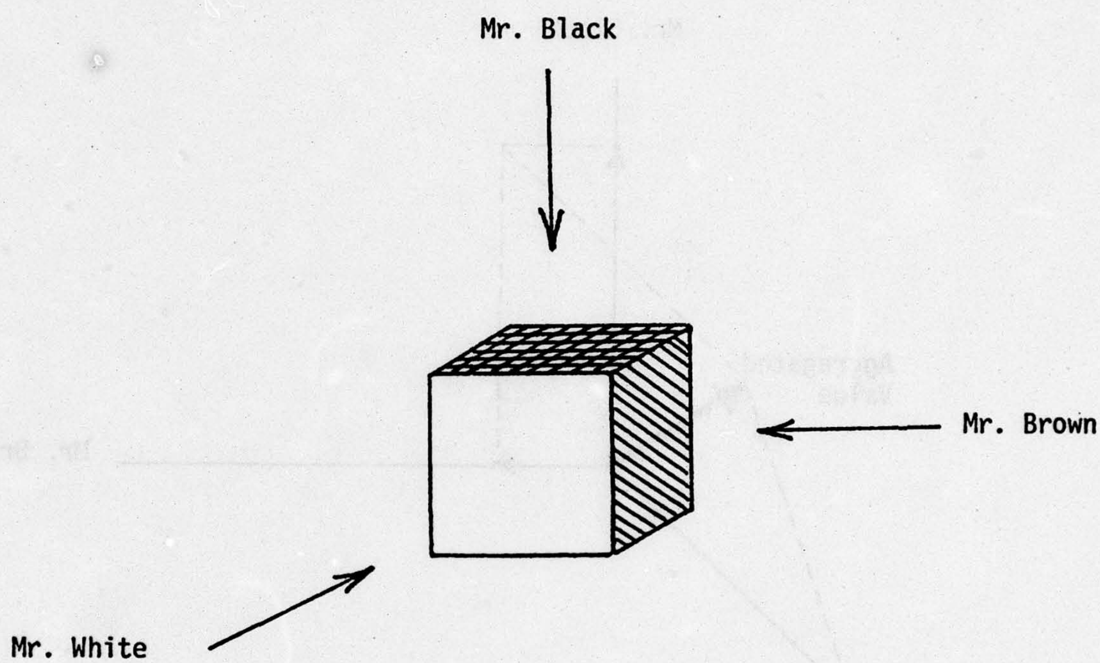



FIGURE 4-4. ORTHOGONAL PERSPECTIVE

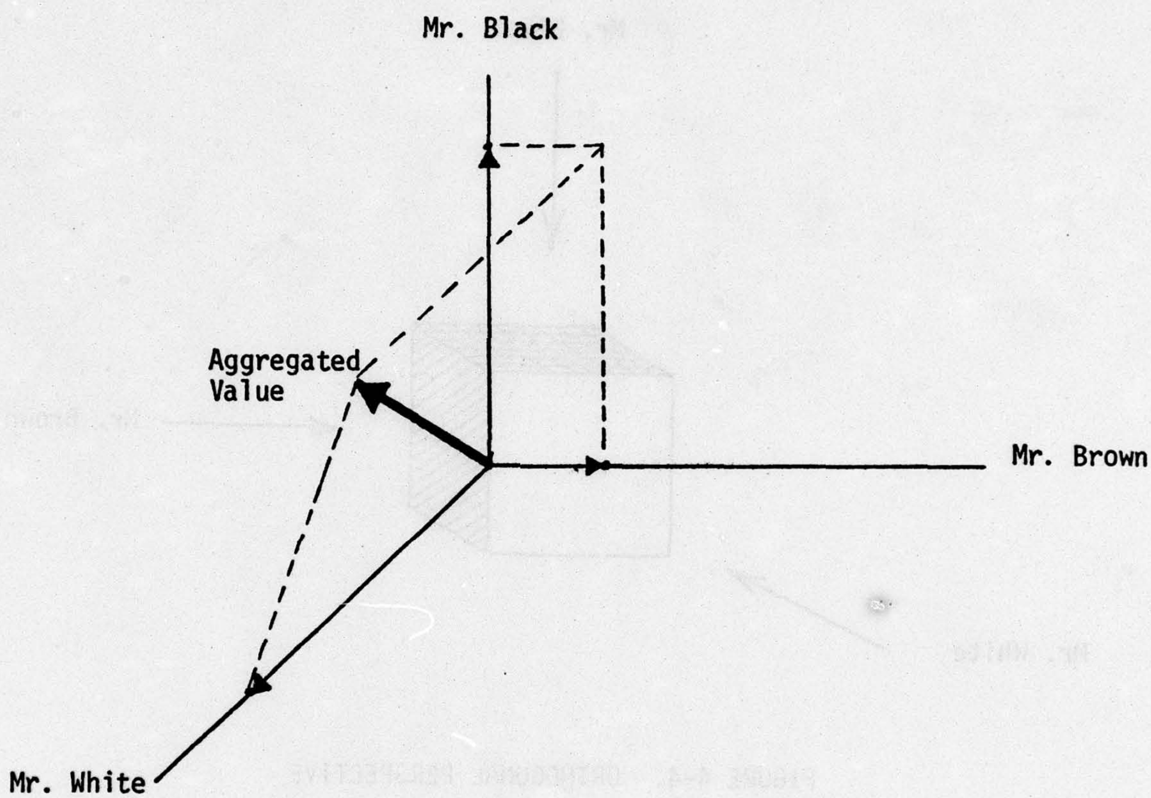



FIGURE 4-5. AGGREGATED PROBABILITY VECTORS

It now remains to combine the two formulas for those cases where the group falls between $\delta = 0$ and $\delta = 1$. This can be done by a simple linear combination:

$$P_j = (1 - \delta)f(P_{ij}) + \delta\hat{f}(P_{ij})$$

where f is the formula for mutually-exclusive backgrounds and $\hat{f}$ is for identical backgrounds.

4.1.3 Weighting. It may be desirable to incorporate weights for the individuals in the group reflecting their degree of expertise. A set of weights $\alpha_i$ is applied to the group and can be placed in the formulas as follows:

$$\delta = 1 \quad P_j = \sum_i \alpha_i P_{ij}$$

$$\delta = 0 \quad P_j = \frac{\sqrt{\sum_i (\alpha_i P_{ij})^2}}{\sum_j \sqrt{\sum_i (\alpha_i P_{ij})^2}}.$$

4.1.4 Conclusions. A number of probability aggregation methods have been developed. These methods include averaging, weighted linear combination, pari-multial, conjugate probabilities, expert model, and probabilistic approach. The sequence in which the methods appear represents the increasing order of mathematical sophistication and decreasing order of practicality for implementation of these methods.

Among different methods for aggregating probabilities, the weighed linear combination seems more attractive. Although the method is represented in a very simple mathematical frame, the results of many studies have

recognized its application to be more acceptable than that of other methods. Studies show that a linear combination procedure is the most accurate indication of the way people integrate several probability distributions into a single distribution (71% of cases in Winkler and Cummings study of linear combination versus conjugation probabilities). Linear combination provides the best fit (least squares) to the majority of the subjectively generated distributions (76% of cases in Winkler and Cummings study of linear combination versus conjugate probabilities). Furthermore, the ease of implementation suggests the utilization of a linear combination for the part of the spectrum which represents individuals with identical expertise.

However, as we get closer to the other extreme of the spectrum, utilization of a linear combination method becomes less proper. The aggregation formula with a linear component and a nonlinear component developed in the previous sections matches such an observation. For a group with identical expertise (intergroup expertise correlation factor $\delta = 1$) the coefficient of nonlinear part is zero and the formula becomes a weighed average. As the correlation between different participants expertise decreases, the coefficient of the linear part also decreases while the coefficient of the nonlinear component increases. This trend continues until we reach a group with mutually exclusive expertise (intergroup expertise correlation factor $\delta = 0$) where the nonlinear component is eliminated and the formula becomes a geometric average.

A primary design objective was the development of a procedure adaptable to all points on the spectrum of different decision making groups (i.e., adaptable to groups with different degrees of dependency among participant's expertise).

## 4.2 Tree Generation

A method similar to the one proposed in Leal (1976) and Leal and Pearl (1977) is selected for the tree generation algorithm. During the group decision making session the consensus (or aggregated) utilities are assigned to the tip nodes of uncompleted decision tree as provisional values. A sensitivity analysis performed based on the provisional values identifies the more promising node which will be the subjects of expansion.

The sensitivity differential of a node is a measure of required changes in the provisional value of that node to cause a change in the choice of the most promising node (the node candidate for expansion). The following two-step process leads to a generalized recursive procedure which is used for finding the sensitivity differential of any node in the tree with respect to the initial decision node:

$$S(\Gamma(n)) = \begin{cases} \dfrac{S(n)}{P(n)} & \text{for an event node } n \\ S(n) + V(n) - V(\Gamma(n)) & \text{for a decision node } n \end{cases}$$

where: $\Gamma(n)$ is the successor of the node n, $P(n)$ the probability along the branch from n to $\Gamma(n)$ and $V(n)$ the provisional value of node n. Using an aggregation method similar to the one for probabilities, the group sensitivity differential, $S_g(n)$, is calculated and the node with the lowest sensitivity differential is considered to be crucial and should be chosen as the next to expand.

It may be argued, however, that the factor which determines the node to be selected for expansion is not the absolute sensitivity differential, but the relative sensitivity $S_r(n)$ which will be calculated as the following (Leal 1976):

$$S_r(n) = \frac{\sigma_{vg}(n)}{S_g(n)}$$

where:

$\sigma_{vg}(n)$: the group anticipated variation in the provisional value of node n which is likely to take place by further refinements (error in the group provisional value)

$\sigma_{vg}(n)$ can be assessed by any of the two methods proposed in Leal (1976) for estimating $\sigma_v(n)$:

1. Ask the decision maker directly to assess the reliability of his value judgment v(n), in the form of a utility interval.

2. Assume a reasonable reliability model.

If individual reliability measures, $\sigma_v(n)$'s, can be elicited directly from the group participants, the first method is used and the group reliability measure then will be caluculated by a method similar to the one proposed for the aggregation of probabilities. If the direct assignment of the reliability is not a practical task for the group participants, then the second method can be used. The use of a simple function such as $\sigma_{vg}(n) = a+b\ v_g(n)$ is suggested for this case.

Since no research comparing the two methods has been performed, one alternative is to implement both methods initially and to evaluate the effects of them on the acceptability and truthfulness of the result. The evaluation of the proposed alternative requires the assumption of a reasonable distribution function for P(V*/V), where V* is the true value. There has

been no research leading to the best distribution function for this purpose. This fact may characterize the question of the selection criteria as one to be attacked during the experimentation phase. The ease of implementation, at this point, may be considered as a secondary selection criteria.

# 5. SOFTWARE DESIGN

Software development for the Group Decision Aiding project is proceeding with the design of an on-line interactive group elicitation program and the development of color graphics support programs. The preliminary design for the group elicitation program is complete and detailed design has just begun. Most of the software to generate the graphic displays is being obtained directly from Rand Corporation. Perceptronics and Rand have similar Genisco graphics systems and there should be little difficulty in adapting their software for use with the decision aiding system.

The software design is being conducted in a top-down fashion using a structured Program Design Language (PDL). By producing a detailed PDL design Perceptronics will supply a well-documented decision aiding system that is easier to implement and will meet near-term needs for modification, as in the second-year program, and transference to other ARPA sites when the project is complete. At present it is planned to implement the elicitation program in LISP while coding the color display software in C. C is a high level implementation language available under UNIX which encourages modularity and good program organization.

## Preliminary Design

The decision aiding system will consist of four major modules described by Figure 5-1. These include:

(1) Decision Support
(2) Training
(3) On-line Briefing
(4) On-line User Assistance

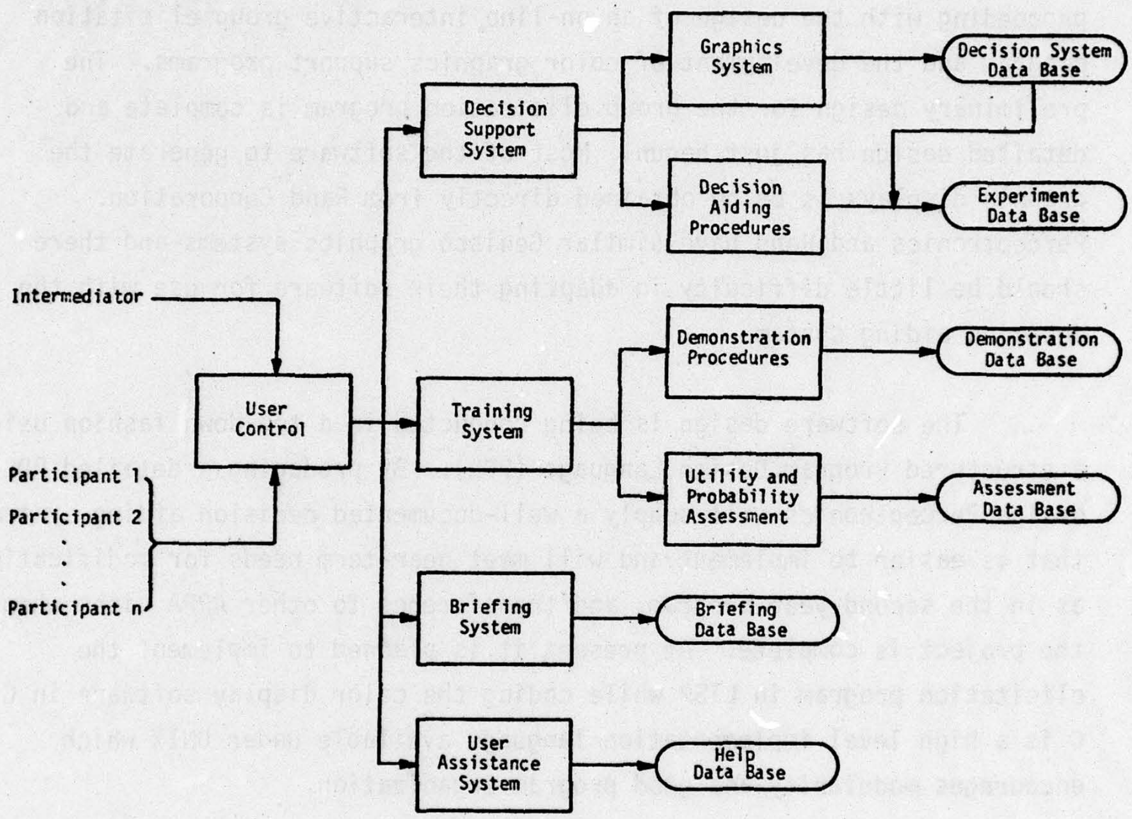



FIGURE 5-1. MAJOR SYSTEMS AND DATA BASE

The decision support module contains the programs for controlling the elicitation, display, and modification of the decision structure. The training system is used to demonstrate group procedures and interactions in using the decision aid and to obtain calibrations on individual utility and probability assessments. The briefing module provides on-line access to briefing materials such as maps, diagrams, messages, and so forth. Finally, the user assistance module supplies general to detailed information on how to use the decision aiding system.

Primary emphasis is on the design, implementation, and evaluation of the decision support module. Interfaces for connecting the remaining three systems have been specified to insure their compatibility within the overall system.

## 6. COMPUTING AND DISPLAY RESOURCES

During the report period work began on installing hardware and software resources to support the Group Decision Aiding project. A Digital Equipment Corporation PDP-11/45 was delivered and installed. The 11/45 computer system has 64K words of memory management hardware, two cartridge disk drives, and a 30 cps hardcopy terminal. All software for the Group Decision Aiding project will be written on the 11/45.

To insure the greatest compatibility and transference of developed software a UNIX operating system was installed on the 11/45. UNIX is a highly regarded general purpose, multi-user interactive, operating system which is becoming a standard in the ARPA community. Work began on configuring UNIX for Perceptronics hardware configuration and developing basis support software. UNIX is now up and running in multi-user mode on the 11/45.

Presentation of group information will be done through the Advent Model 750 Videobeam Color Television Projection. The projector was bought from 4C Corporation of California who specially selected the tubes and modified the Advent electronics to enhance its alphanumeric display performance. The Advent was installed in Perceptronics group display facility and produces high quality large screen color displays.

Two Interface Technology Model 736 data entry terminals for use by group participants were purchased and installed in the group display facility. Each terminal has eight indicator panels which may be lit separately or in combinations under computer control, an eight digit LED display, and a set of 19 keys. Then keys are reserved for numeric data entry while the others may be programmed for special functions (e.g., such as voting).

A Beehive B-100 terminal for the group intermediator was purchased. The B-100 has a full alphanumeric keyboard, 16 function keys, cursor addressing, and a full set of cursor and edit control keys. The B-100 terminal will also be used to support programming on the 11/45.

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# APPENDIX A

# SUBCONTRACTED WORK

# CACI WORKING PAPER 1

# MULTIPLE TREES, A GROUP AND SOCIAL CHOICE

## MULTIPLE TREES, A GROUP, AND SOCIAL CHOICE

Two major research problems in the project are eliciting a tree from a group of persons and merging independently constructed trees. This paper argues that both problems are variants of the general problem of social choice. If the premise is correct, it is important that all members of the research staff agree that no perfectly general methodology or algorithm can be developed if it is to be "fair." By implication, any "solution" to the research issues must exploit the peculiarities of the crisis management situation if it is to be reasonable. The goal must be to adopt or develop an unfair means to resolve social choices that does not simultaneously violate the overall goal -- a functioning, useful decision aid for crisis management.

The arguments used to advance the major contention -- that social choice is the central problem -- are nontechnical and informal. At this stage, there would seem to be no advantage to a formal statement. All members of the staff are familiar with the literature and will recognize the basic issues. The real issue is whether or not the match between social choice and the research project is close enough to worry about. In presentation, the argument is a series of problem statements. Readers are asked to examine these "problems" for similarities and differences. If clear differences can be identified, it will be a substantial advantage. If similarities predominate, then work must proceed under the assumption that a "solution" to one subproblem may dictate the solution to another.

## TREE MERGING -- ALL IN FAVOR OF THE SILVER MAPLE SAY AYE

The task of merging two or more independently constructed trees is intuitively "closer" to the social choice problem as it is usually stated than is the task of eliciting a tree from a group. The mechanics of the latter task serve to complicate the issues and become the focus of attention rather than the (alleged) underlying issues. Consequently we begin by

looking at tree merging. We assume that at least two (and commonly three) trees exist, that they are complete, and that they and not their creators are all that is available. We further assume, to be sure we are all talking about the same issues, that the builders are informed, perceptive decision-makers. This last assumption insures that there is no <u>a priori</u> means to discriminate among them that would be preferred to flipping a coin.

We begin by considering one of the most commonly enunciated problems of tree merging -- probability assignments that differ across trees. In particular, suppose at a particular node, three available trees specify probabilities as depicted in Figure 1A. Because the probabilities are not in <u>perfect</u> agreement, a rule to "rectify" these assignments must be developed. And the problem is the nature of that rule.

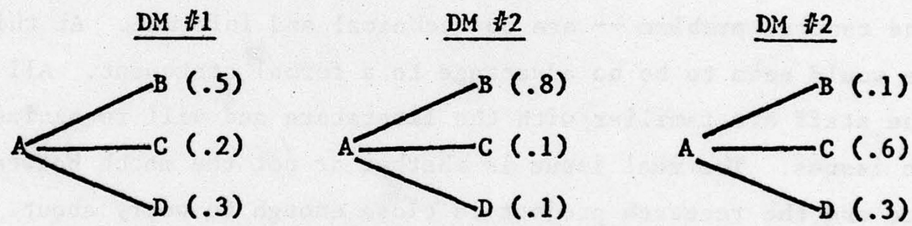


Figure 1A

It will be helpful in this discussion if language does not inadvertently become the focus of attention. Consequently, a forced agreement will be necessary. Let us agree that it will not matter whether Node A is an event node or a decision node, and accept the same stipulation about all other nodes. The phrase "state of the world," or "states" for short, will be used interchangeably with nodes. The state may be a "decision to be made" or an "event." While some subtle and some not so subtle implications are buried in this agreement, the readers' good will is requested. The intent is to get on with the story and require the reader to work out those implications he believes important.

Viewing Figure 1A, there are at least three responses commonly forwarded:

1. How do we resolve the conflict?
2. Is there a conflict?
3. How much of a conflict is there?

It is argued here that these questions can be shown to depend on three implied criteria for group decision-making:

1A. Rank orders are of dominant importance

2A. Adopt serial dictatorship.

3A. Disregard independence from irrelevant alternatives by depending on strengths of individual preferences.

To proceed, a little shorthand will be convenient. We will follow the convention that XpY means X is preferred to Y; that XnpY means X is not preferred to Y; and that XiY means XnpY and YnpX. Using this scheme, an ordering of preferences can be created as in Figure 1B. If the fundamental question (1) is addressed to the problem of Figure 1A, then Figure 1B presents essentially the same problem. The only way to resolve the different orderings is to establish a social decision rule. Unfortunately, from Arrow we know that no "fair" decision rule exists. If a resolution is to be made, fairness must be violated and (at least) one of Arrow's axioms must be relaxed. The question is which one.

| DM #1 | DM #2 | DM #3 |
|---|---|---|
| BpD | BpC | CpD |
| DpC | CiD | DpB |
| BpC | BpD | CpB |

Figure 1B

Question (2) to Figure 1A suggests that nondictatorship is (probably) the appropriate axiom to drop. If democracy is adopted, then there is no conflict for the presentation in Figures 1A and 1B. Loosely speaking, it's 2 to 1 on every pair except C and D; the top of the ordering is identified. Again the problem is from Arrow: Democracy always reduces (or can be reduced) to serial dictatorship. If the argument is not coming back immediately, Figures 2A and 2B should be helpful. <u>Any</u> group ordering developed in this case would degenerate to dictatorship.

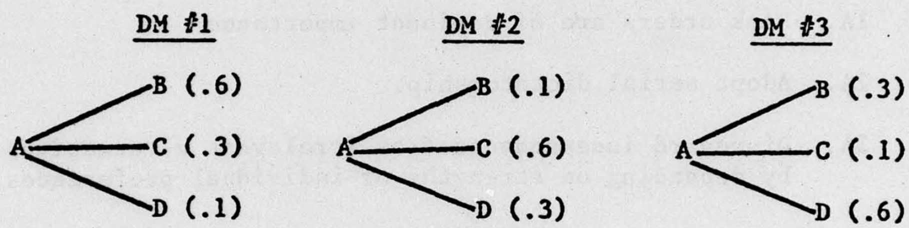


Figure 2A

| DM #1 | DM #2 | DM #3 |
|---|---|---|
| BpC | CpD | DpB |
| CpD | DpB | BpC |
| BpD | CpB | DpC |

Figure 2B

Question (3) to Figure 1A really presents the most interesting case. The problem is to examine the implications of assuming degrees of conflict. The easy variant has just been discussed -- a partial "agreement" on the top or bottom of the ordering. The more difficult variant is to attempt to extract information from the probability assignments rather than the probability as preference orderings view. Before proceeding, there are two points to be emphasized. The first is an assertion: Absolutely <u>no</u> manipulation of numbers will resolve 2A if that manipulation is not the arithmetic equivalence of dictatorship. The second point is a question

to the reader: Honestly ask yourself if you would want a decision rule to distinguish between 2A and 2C, and why? Is it "consumer sovereignty?"

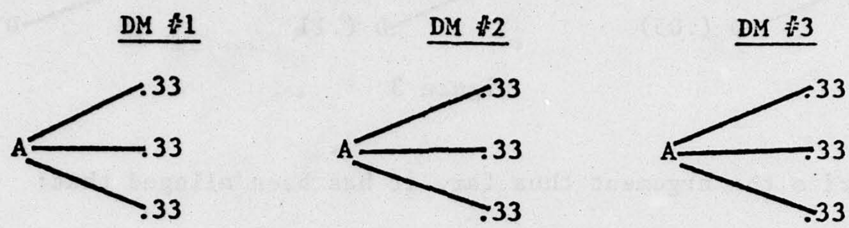


Figure 2C

Getting back to the discussion, we want to ask whether we can employ the probability assignments directly. Essentially, we want to ask if the two triplets (.6, .3, .1) and (.8, .1, .1) can be used to tell us anything. Quite obviously, if we accept that the numbers matter, we adopt some variant of the Weber-Fechner just noticeable difference (jnd) idea. Assume we do. What is the jnd we hope to employ? It is emphatically not true that .6 - .3 = .3 says anything distinct from .8 - .1 = .7. We must know how many jnd are in .3 and how many are in .7. Notice also that in any strict application of jnd, .1 - .1 = .0 is not different from .3 - .1 = .2. True, we can assume that .0 represents no jnd's, but that it is not equivalent to assuming .3 - .1 = .2 represents at least one jnd.

Our lives are made substantially more difficult by the requirement that whatever rule is chosen, probabilities summing to 1.0 must be assigned. If we adopt any variant of jnd, Figure 3 represents the same logical problem as does 1A and 2A despite the intuitive sense of "no conflict" in Figure 3 and absolute "no conflict" if rank orderings are adopted. Finally, whatever is done to create a number between zero and one that is assigned to a branch will mean that a (possibly nonunique) linear combination of individual probabilities is involved. Setting aside the issue of whether the same linear combination is (would be? should be?) used on other branches, we have made one more assumption: that jnd's are strictly (exactly) comparable across individuals.

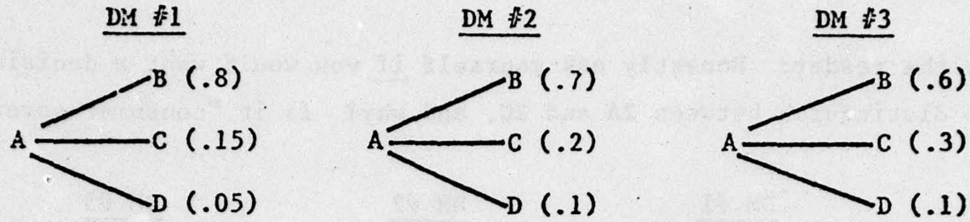


Figure 3

To summarize the argument thus far, it has been alleged that:

1. Any occurrence of different probability assignments requires that a social decision rule be adopted.

2. Any social decision rule will not be fair in the sense of Arrow.

3. Inferences from probability assignments require jnd thesis as a necessary but not sufficient condition, and

4. Assignments of "group" probabilities require strict interpersonal comparison as a necessary condition.

## WHAT IF IT'S NOT A SILVER MAPLE?

The cases and examples thus far have been sufficient to cause despair, but the worst is yet to come. Each figure has followed a remarkable similarity despite all the differences. The real unpleasantness begins with Figure 4. We can speculate about probabilities in this case, and some ideas will be offered, but the real question is whether Figure 4 is different from Figures 1A, 2A, 2C, and 3.

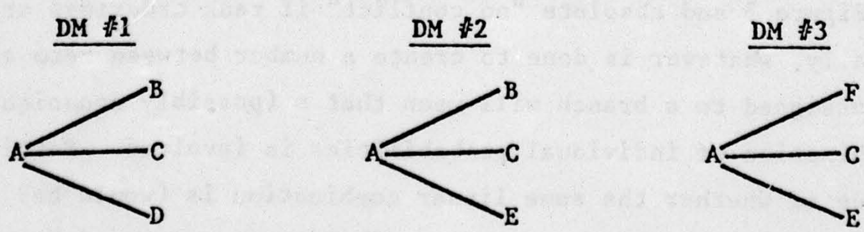


Figure 4

If we consider the actual research project rather than an abstract set of nodes or states, Figure 4 is the single most important phenomenon to worry about. In practice, we know that no analyst can physically construct a decision aid (tree) for a complex crisis situation that is exhaustive and finished in less than 3 hours. (We omit the issue of an exhaustive tree for a complex situation <u>regardless</u> of time.) In practice, an analyst is asked to build a tree that concentrates on the "likely" situations and captures the "range" of outcomes he views as possible. If we are presented with a real world Figure 4 situation, then it seems reasonable that the basic justification of building multiple trees has been realized. For whatever reasons (remember, however, that degrees of incompetence are ruled out), analysts hold different views of the most probable course of future events. Somehow, we must merge these different views into an "improved" aggregate view. The questions are how to do it and the implications of the adopted method.

Conceptually, the situation in Figure 4 <u>could</u> arise in the following manner. Each analyst imagines an exhaustive collection of all future states of the world. The request to identify the most likely (or most anything that functions as a filter) means the analyst excludes some unknown number of states from the tree. The process of exclusion could occur in any number of ways, but two examples are provided:

1. Exclude all events with "small" probabilities until the sum of the excluded probabilities approaches a critical level. Record all other events.

2. Exclude all events whose probabilities are individually below some critical level. Record all other events.

Each of these rules (and the parallel, most probable versions of each) implies that the analyst has incorporated a variant of jnd into the analysis of tree construction. The reported events have probabilities above (on whichever standard) the jnd level. The <u>reported</u> probabilities, however, because they do sum to one, are conditional on the exclusion rule

and the jnd exclusion level. If the rule and the jnd are common (or equivalent) among all analysts, then the interpersonal comparison of probability assignments is valid (1) up to a linear combination, and (2) provided exactly the same combination is used for all (common?) branches from a node.

Consider Figure 5A. The common state away from A is C, and both trees record the same probability. To identify clearly the basic choice to be made, example figures are provided in 5B and 5C for hypothetical merged trees. In 5B, arithmetic means are computed for each node after "filling" in the missing node and assigning a zero probability. We may quibble over the exact process, but the point is that the same linear combination is applied to all branches.

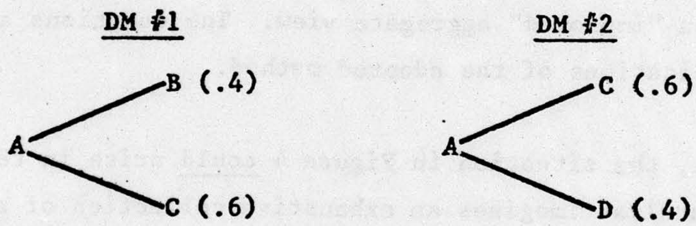


Figure 5A

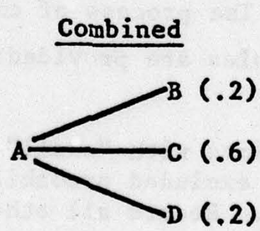


Figure 5B

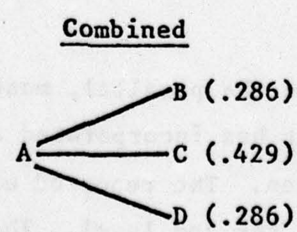


Figure 5C

Figure 5C takes a different approach, closer to set theory ideas. We count the intersection of the two analysts' views only once as it is the same state. (The contention that states and probabilities are interdependent is explicitly ignored.) The union of the two analysts' views is then 3 possible states whose "probability" totals 1.4. Simply rescale to a total of 1.0 (divide by 1.4, for example, .4/1.4, .6/1.4, .4/1.4) to produce Figure 5C.

Figure 5B meets the requirements of jnd and strict interpersonal comparability. A linear combination is used, and the same combination is applied to all branches. It is not clear that 5B is not also true to the fundamental idea of jnd's.

Interpersonal comparisons <u>are</u> made. The critical jnd <u>is</u> observed, and it might be argued that the observance is "more neutral" than the zero probability assignment used in 5B. However, Figure 5 is a simple case. As examples, the reader is invited to examine a case of incompatible assignments on state C, a case of multiple intersection with incompatibility on one or more of the common nodes, and a case of no common nodes to show that the rule reduces to the rule of 5B in that particular instance. It should be clear that rules 5B and 5C are not equivalent for cases of exact overlap.

## Group Elicitation

The single biggest problem associated with group elicitation of a tree is also the problem of social choice. Each issue discussed previously applies exactly in the group setting. It may <u>appear</u> that the problem is made more simple by having the collection of decision-makers in the same room. In fact, it becomes worse. Whatever the pro's and con's of a particular rule to be used to resolve social choices, the limitations of the rule are known and the individual choices are known. In a group setting, the shrewd guess is that the full set of individual choices will never

be known. Further, the social rule can be expected to be determined by the mechanics of elicitation.

The assertion that individual choices will never be known is trivially true unless the group builds a tree after each member has separately constructed a separate tree. Otherwise, all construction steps are conditional on the group's treatment of the first node and branches from it. The conditional nature of all subsequent statements by individual analysts constitutes the real problem because (1) strategy becomes an admissible behavior, and (2) the mechanics of elicitation may determine the result.

Consider the simplest possible situation for the interaction of strategy and mechanics: the group as a legislature. It is well known that the order of pairwise comparison can determine the "group preferred" alternative from a 3 by 3 set. Because we are eliciting a tree in a sequential environment (simultaneous software is presumed to continue not to exist) the unintentional effect is as if a random table replaced Robert's Rules for a group discussion. More exactly, the criteria used to determine the order of tree expansion may inadvertently <u>determine</u> the outcome, unless, of course, strategies are developed.

There would seem to be no <u>a priori</u> reason to prohibit strategy by members of the group, and the strategy may or may not require concealment of true preferences. Note carefully that a two-level game must (may) be played. The within-group game to resolve existing state differences interacts with the game to determine the expansion to be pursued in the next stage. It is asserted without support that analysts are sufficiently intelligent to attempt to play a compound game of this sort. The question becomes whether it is possible or desirable to frustrate these gaming efforts or to attempt to exploit them.

The final issue confronting group elicitation is group think, or risk-shift. About all that is known with confidence is that it occurs. As a

result, it is not possible to build it out of the elicitation algorithm. It may be the case, however, that an explicit risk-averting treatment should be built into the tree evaluation or roll back procedure. One "normal" and one "risk-averse" treatment might be sufficient to induce the group to reexamine the "normal" or standard tree to protect against a potential shift toward risk.

CACI WORKING PAPER 2

CRISIS MANAGEMENT CONTEXT

## INTRODUCTION

This paper reviews information available about the "context" of crisis information. It is predicated on two assumptions.

- That the overall purpose of the project is to produce a system that will allow effective use of decision network technology to aid in military crisis management, and

- That the impact of any technology on performance, and particularly the impact of executive aid or decision-making technologies, is related not only to the technology but also to the context within which it is operative.

The first assumption is a simple statement of fact. The second is a reflection of the work of contingency theorists such as Lawrence and Lorsch (1967), Vroom and Yetton (1973), and Carlisle (1974). Basically, contingency theorists contend and their research tends to show that the entire system of factors present in an organizational climate operates in tandem to facilitate or inhibit performance. Given significantly different environments, widely varying performance levels are likely. Application of this approach to decision aid technology has been carried out for the Office of Naval Research by CACI (Spector, 1976), where the evidence has been consistent with the hypothesis that acceptance and use of decision aids are related to the context in a systematic manner. Hence, contingency theory implies that the operating environment should be considered in developing new tools.

This paper briefly explores two views of the crisis management context. The first is a descriptive view of military crisis management activity. The second is an historical description of crisis characteristics, including their implications for crisis management aids.

## DESCRIPTIVE VIEW

In a recent review of crisis management, Tom Beldon argued that warning and crisis operations have a broader series of objectives than is often thought to be the case. These, he argued, are:

1. Avoid or head off a potential crisis situation (crisis avoidance).

2. If (1) fails, manage the crisis so as to satisfy national policy objectives without resorting to military force.

3. If (2) fails, use conventional force and diplomatic efforts to avoid long or severe conflict, conventional or nuclear.

4. If (3) fails, end the conflict on terms as favorable to interests as possible before Armageddon (Belden, 1977).

The national military decision process designed to handle the interactions that must take place to manage crisis situations effectively is comprised of several nodes linked together in varying degrees of specificity. In its most normal form, there would be a three-tiered system for both intelligence and operations. Thus, Figure 1 lays out the nature of the nodes as they exist in the South Korea case. Here the onsite commander will have a military intelligence group attached to his command. The two on-scene groups may vary from two persons to two formally organized groups, depending on the size of the command. In Korea, it varies with the level of command. For planning purposes, however, it is fair to assume that they are well organized and that they communicate frequently.

At the next level, CINCPAC, the two groups are IPAC and CINCPAC/J-3 for intelligence and operations. These two groups rarely communicate with

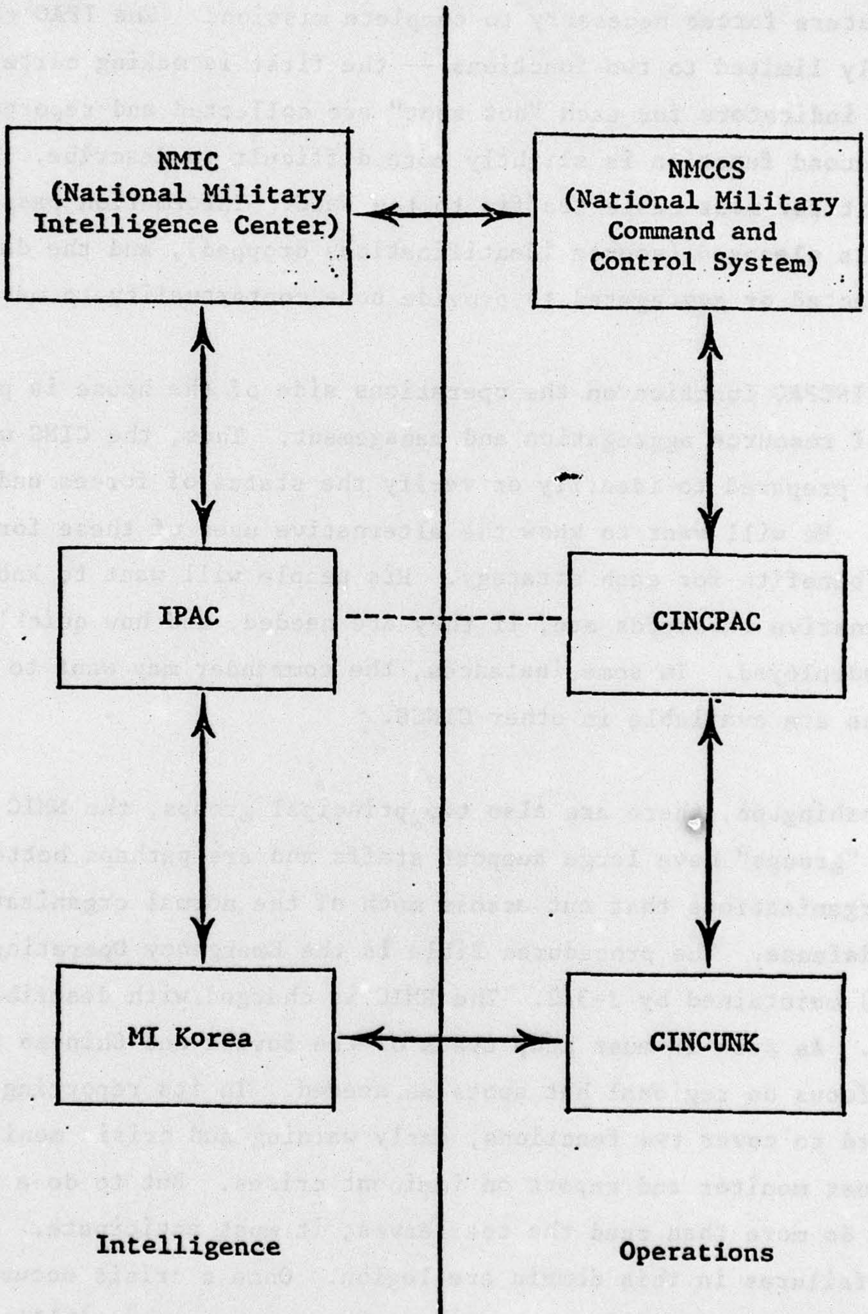
NMIC
(National Military
Intelligence Center)
NMCCS
(National Military
Command and
Control System)
IPAC
CINCPAC
MI Korea
CINCUNK
Intelligence
Operations

Figure 1

each other. IPAC will concern itself with supporting the NMIC, and J-3 coordinates the on-scene effort. There appears to be little interest on the operations side of the house to intercept intelligence and to "guess" the future forces necessary to complete missions. The IPAC effort is largely limited to two functions -- the first is making certain that 150 or so indicators for each "hot spot" are collected and reported regularly. The second function is slightly more difficult to describe. They are the conduit for most cable traffic to the NMIC. Information passing through IPAC is cleansed (source identifications dropped), and the data are abstracted or aggregated to provide some contextuality to messages.

The CINCPAC function on the operations side of the house is primarily one of resource aggregation and management. Thus, the CINC will want to be prepared to identify or verify the status of forces under his command. He will want to know the alternative uses of these forces and the cost/benefits for each strategy. His people will want to know where alternative resources are, if they are needed, and how quickly they can be redeployed. In some instances, the commander may want to know what forces are available in other CINCS.

In Washington, there are also two principal groups, the NMIC and the NMCCS. Both "groups" have large support staffs and are perhaps better thought of as organizations that cut across much of the normal organizational chart for defense. The procedures Bible is the Emergency Operating Procedures (EOP) maintained by J-3/2. The NMIC is charged with describing the situation. As such it must keep track of the Soviet and Chinese at all times and focus on regional hot spots as needed. In its reporting, the NMIC is tasked to cover two functions, early warning and crisis monitoring. Thus, it must monitor and report on imminent crises. But to do a good job, it must do more than read the tea leaves; it must anticipate. Its successes and failures in this domain are legion. Once a crisis occurs, a substantially enhanced crisis alert team takes on the responsibility of interpreting the message traffic, analyzing it, and producing estimates of what

will happen next. But the early warning function must still be maintained. It frequently answers the "what if" questions of crisis managers.

On the operations side in Washington the chairman's support group comes primarily from J-3 and J-5. This collection of skills and experience is brought together to answer the important question: "What should we do?" At the working level, this breaks into two groups. The first group, the EOP Crisis Management Team, must receive the intelligence information and the status of U.S. forces information. It must identify logical courses of action and the tradeoff involved in each and present them to appropriate command authorities. Another group, the SAGE cell, attempts to look ahead organizationally and to allocate resources so as to be prepared to respond to command requests when they occur.

Coordination between operations and intelligence is located in Washington because of the role of the Chairman of the Joint Chiefs in the crisis situations. It is also ensured at the on-scene level because of the immediacy of the conflict and its impact upon the command. But it is rare at the CINC because of the twofold nature of his role. He is a conduit for intelligence and a crisis management partner for managing U.S. forces. Thus, his main report function is regionwide information on the status of U.S. forces.

Consider a hypothetical sequence of events in this chain of command with emphasis upon the Washington node. Our NMIC watch officer comes to work early on a Tuesday night (2 a.m.) and begins reading cable traffic coming in from his region, China and the Far East. There is a report from IPAC alleging that North Korean soldiers violated the DMZ between North and South Korea, fell trees, started fires, and herded apparently diseased cattle into South Korea before fleeing across the DMZ. The watch officer makes a report (Figure 2) and calls a conference of other watch officers immediately to see if they have corroborating evidence. He asks IPAC if there is any supporting or disconfirming evidence elsewhere in the region.

(Security Classification)

WARNING ESTIMATE

Information as of:

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FROM:

TO:

THERE IS A % PROBABILITY THAT:

1. HOW MANY:
2. (OF) WHOSE:
3. WHAT/WHO:
4. WHERE
5. WHEN:
6. (VERB PHRASE):
7. HOW MANY:
8. (OF) WHOSE:
9. WHAT/WHOM
10. WHERE:
11. WHEN

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12. HOW-/-CONJUNCTION

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13. SOURCE(S):
14. ADDITIONAL INFORMATION:
15. COORDINATION COMMENTS:
16. PREPARED BY: Phone No:

(Security Classification)

Figure 2

Source: Belden (1977)

IPAC reports that South Korean troops have been ordered to follow the raiders back across the DMZ and retaliate. They left 2 hours ago, but the on-scene commander has not heard from them since.

Meanwhile, via the "meet me" by bridge conference with other watch officers from State and the CIA, it is learned that there has been a series of high level diplomatic meetings among North Koreans, Chinese, and Russians.[1] The Russians have apparently remained in Pyongyang, but the Chinese went home after less than 1 day.

While the three watch officers are discussing whether others should be notified, the military watch officer says he just received information that the South Korean patrol has been repulsed by a much larger North Korean force coming across the DMZ. At this point all watch officers break off the conference and make reports to their superiors. From this point on the NMIC will continue to monitor the situation, but it will report to a crisis emergency operations team set up in the situation room of the NMCCS through an analysis team made up of DIA area experts called in to strengthen the interpretation capability of the NMIC. The EOP team will ask CINCPAC for the status of forces on all local and potential troops. It will also ask if the on-scene commander wants to take any action. The point at which actual action takes place is probably further down the road, but from this point on the EOP group will array alternative actions and forces capable of carrying out the suggested order of battle.

If indeed the forces from North Korea make contact with South Korean or U.S. troops in South Korea, then the EOP group will be bolstered with the addition of a permanent crew of flag officers who will offer suggestions to higher-levels (WASG) and make immediate decisions. CINCPAC will

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[1] See Beldon (1977) for a discussion of the "meet me" conferencing.

see that decisions are staffed and that forces are deployed to support these actions, including likely follow-ups. At the same time, the on-scene commander will be fighting the enemy.

Note that the "crisis" has just begun, but at least two groups are already developing alternatives and making recommendations. One of them has immediate, continuing responsibility for recommending timely actions. A second is engaged in contingency planning-repositioning forces, which may be needed later if the situation deteriorates, moving supplies, and so forth. On the intelligence side, alternative future actions by the adversary are identified and key indicators found to discriminate among them.

The time available is different for different groups. All groups have counterparts at the other levels of command. All must be prepared to operate around the clock, with interchangeable personnel (hence continuity of group membership cannot be assumed). The stress levels are generally low in the CINC and national centers (except for critical moments) because they are removed from the scene and staffed largely with experienced officers. To the extent that political appointees are on the communications net or present at the national center, however, there is likely to be greater tension and lesser crisis experience.

## HISTORICAL DESCRIPTION

This section describes historical data and trends in the military crisis context. It summarizes previous ARPA-sponsored research (Hazlewood and Hayes, 1976) and draws implications for executive aid technology.

- Ninety percent of all crises occur in foreign countries. Hence, geographic distance and a CINC level command center between the national command authority and the operating units must be assumed. The 3-level situation implies that different groups in different locations with different information will be involved in most crisis management actions.

- Nearly half of all crises last 30 days or more. Another 20 percent last more than 1 week. This implies task forces working in shifts, so personnel continuity cannot be assumed. It also implies a series of decisions in a changing situation rather than a single situation and selection of options.

- A substantial number of crises (about one-third) occur with no warning. Hence, the system should be capable of immediate use, and time may be a serious constraint.

- Periods of tension or increased readiness occur in about 70 percent of all crises before crisis management activity is initiated. Hence, prestructured options and some information about the situation are likely to be found in the decision group. This can lead to decreased flexibility and greater within group discussion.

- One-third of U.S. crises have involved another large power. Hence, nuclear decisions may have to be made rapidly.

Separate analyses were also carried out on the types of problems experienced in U.S. crisis management. These involved a sample of a larger list of situations.

- Emotional issues were present in 70 percent of the crises. Hence, sterile exercises will not "test" the system.

- Three-fourths of all situations included limits to military decision latitude. Hence, explicit statements of constraints may be wise.

- Half of the situations produced conflicts over U.S. policy in the international arena. A clearly articulated set of policy guides cannot be assumed.

- About 60 percent of all situations since 1946, and an increasing percentage over time, involved extensive interagency coordination within the U.S. Government, which delayed decisions.

- Intelligence about the situation was inadequate in one-third of all cases. Delay in obtaining facts was a problem nearly 40 percent of the time. This, too, has worsened over time. Perfect information, or even agreement on the situation definition, is a poor contextual assumption.

- Failure to recognize important information has been a problem in nearly half the situations. Again, perfect information is a very poor assumption.

- Multiple crises have moved from virtual nonexistence before 1954 to 28 percent of all cases in the 1966-1975 decade. Hence, decision-makers may be distracted and/or working on compound problems.

Note that this research does not focus on the human factors -- the attributes of the human beings involved in the decisions. It is recommended that this factor also be considered.

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CACI WORKING PAPER 3

NETWORK ELICITATION PROCEDURES

NETWORK ELICITATION PROCEDURES

The process of network elicitation in a crisis management context is always a trade off between time and level of detail. By definition crisis decisions must be made in limited time frame. At the same time, networks must be sufficiently detailed to produce useful judgments and communication meaningful alternative and their implications. Hence design of the decision aid, which includes network elicitation must choose to balance time (including time spent on discussions) vs. detail.

Specific Comments on Perceptronics Approach

The Perceptronics/Leal approach to network elicitation appears to waste time and take a chance on creating confusion because it calls for movement from node to node across the network. After two or three layers have been constructed it is extremely difficult for the people involved to remember the context applicable to each node (its parent nodes). This means that they waste time by having to go back and review the previous entry for each tip node being studied. This problem is compounded when a group is involved since confusion on the part of any one member is immediately translated into delay for the entire group.

The calculations suggested in Leal's dissertation for sensitivity and relative sensitivity and the discussion of the need for relative sensitivity measures (page 27-30) are based on a false assumption. As expressed in the text, the gap between the number 5 and the number 10 is not seen as equal to the gap between number 110 and the number 115. If this assumption is correct, ratio scale is not present in the outcome values. But Bayes theorum all major decision analysis efforts, and the roll back calculations used throughout Leal's work all assume the presence of ration scale. Therefore, it seems wise to avoid the relative sensitivity measure and work from the simple sensitivity calculations.

The procedure being suggested by Perceptronics requires that the group specified values for intermediate tip nodes. This presents at least two problems. First, the complex decisions often facing crisis managers and the untrained decision-makers hopefully utilizing the aid, are not likely to produce high quality estimates of tipnode values for branches which have not been thoroughly analyzed and reviewed. Second, there is no evidence that estimated tip node values for incomplete branches are close to the values which would be found if the branches were fully explored. It would appear that at a minimum this should be a subject of experimentation. The experimental question would be the accuracy and stability of estimated tip node values when compared with those present in fully elaborate trees.

A final question about the initial set of Leal's procedures relates to the handling of probabilities for decision nodes which represent U.S. choices. The initial formulation calls for ignoring probabilities (whcih automatically assume the probability of 1.0 for some choice). However, when the probability of a U.S. decision is not clearly dominated, i.e., the relative utilities for branches are close, this strategy can lead to false assumptions. Moreover, there are many cases where it is crucial to play out a branch node to locate nonobvious consequences. A number of CACI's practical efforts using networks to explore policy issues have produced this type of finding. The existing Leal procedures would have a high probability of denying the user this knowledge and/or of selecting the incorrect U.S. decision because of nonobvious consequences.

## Recommendation

Based on these considerations and previous discussions it is recommended that full network structures be elicited for at least two layers and then one branch at a time be fully elaborated. This will save considerable time and help avoid contingent decision errors and nonobvious consequences. In addition, since most networks result in repetative structures, particularly on the right hand or late side of the networks, it is recommended that provision be made for identification of repetitive structures

so they can be quickly added to new branches where appropriate. Another way to save time would be to explore the probability of creating a standard set of outcomes with default values reflecting the decision-maker goal structure. These certainly should be changeable if the group feels their context is different, but many symbols could be completed with relatively little change from this set of values. It seems reasonable to consider having one portion of the group creating the tree structure while another portion of the group creates sets of outcomes and places initial values on them. Their may be considerable time saving in this.

The value of Leal's algorithm would appear to lie in sensitivity analysis, rather than structuring elicitation. A completed netowrk could be rapidly and efficiently scanned using Leal's approach to identify the crucial nodes and outcome assignments. This would greatly facilitate the completion of complex efforts and add considerable confidence to the group's networks.